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SOILS AND THE GROWTH OF *PINUS RADIATA* AT CORNWALLIS, AUCKLAND

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(Received for publication, 5 August 1959)

Summary

A detailed survey of pine growth and soils of Cornwallis showed that stunted pines were associated with a particular soil type, the Cornwallis silty clay, classified as a strongly leached brown granular clay, and weathered from andesitic tuffaceous sediments. From an experimental investigation it was concluded that stunted growth had resulted from phosphorus starvation due to restricted root growth. Inferior soil aeration associated with weak development of soil structure appeared to be the primary factor restricting root growth.

INTRODUCTION

During the period 1922-24 a *Pinus radiata* plantation of 630 acres was established at Cornwallis by the Auckland City Council. From the outset, the pines in some areas showed abnormally slow growth rates and today nearly half of the original plantation consists of stunted trees. The present study is an attempt to determine the factors responsible for the differences in growth.

Location and Climate

Cornwallis reserve is a 1,927 acre area of forest and scrub-covered land situated on the north-western shore of the Manukau Harbour (Fig. 1). The pine plantation covers a large part of the low-lying Cornwallis peninsula as well as moderate and steep slopes north of the Titirangi-Huia Road (Figs 2, 6).

Rainfall measurements made at Cornwallis by the City Council Parks Department during the years 1924-48 show that the annual rainfall for this period ranged between 43 in. and 82 in. with a mean value of 57 in.

FIG. 1.—Geographic position of Cornwallis.

The growth season extends from September to April and the rainfall for this eight-month period varied between 22 in. and 47 in. with an average value of 32 in. Two-thirds of this precipitation occurs between September and December, and the rainfall for the period January to March may be as low as 5 in. in some years.

No temperature records from Cornwallis are available, but an indication of the temperature climate may be obtained from records at Auckland, 14 miles away (N.Z. Meteorological Office, 1953). Published figures for the period 1943-50 show that the mean annual temperature varied between 58·9° F and 60·6° F. The mean monthly temperature for the coldest month, July, varied between 49·3° F and 53·2° F, and that for the warmest month, January, varied between 64·6° F and 69·7° F. Mean temperatures for the eight-month growth period varied between 62·3° F and 64·1° F with a mean value of 63·2° F. Light frosts occur during the winter months.

FIG. 2.—Cornwallis peninsula showing healthy stands of *Pinus pinaster* and *P. muricata* on Puponga Point, and the southern end of the stunted *P. radiata* plantation in the foreground.

Photograph: Whites Aviation.

Topography and Geology

The reserve can be divided into two parts of contrasting topography, viz.:

(i) an elevated northern block comprising a broad north-south ridge, 600 to 800 ft in height, and continuous with the interfluve system of the Waitakere hills. West of this ridge the ground falls steeply to the gently graded Kakamatua stream (Fig. 6).

(ii) a southern low-lying (100 to 300 ft) peninsula area of rolling slopes together with the gently dipping slopes east of Mill Bay (Fig. 6).

The geology of the southern Waitakere region, including the Cornwallis area, has been described by Searle (1944). Yellowish-brown feldspathic sandstones and pale grey laminated mudstones of the Waitemata Formation underly most of the peninsula and the elevated terrain to the north. Interbedded with these rocks are yellowish-brown andesitic tuffs and grits; marine bedded sediments which have a common origin with the andesitic breccias of the Manukau Breccia Formation (Brothers, 1954). At Cornwallis, beds of the latter are restricted to the headland of Puponga Pt. Consolidated dune sands of Pleistocene age overlie Waitemata Formation sediments in one localized area on the southern side of the peninsula.

Vegetation

In 1840 the higher ridges, spurs, and upper valley slopes were covered by kauri (*Agathis australis*) forest, but by 1880 all millable kauri had been felled and frequent fires had completed the destruction of this forest. In the valleys, surviving remnants suggest that these communities were dominated by rata (*Metrosideros robusta*) and rimu (*Dacrydium cupressinum*) which were emergent above an uneven canopy of kohekohe (*Dysoxylum spectabile*), tawa (*Beilschmiedia tawa*) and other dicotylous trees.

On the rolling slopes of the peninsula, the presence of a former extensive kauri forest is indicated by the large quantities of gum that were dug from this area. However, the few scanty descriptions available suggest that by 1840 this forest had disappeared. This may have been due to fires lit by the Maori who is known to have used Cornwallis (Karangahape) as a seasonal fishing station (G. G. Mitchell, J. T. Diamond, pers comms, 1957). Part of the peninsula was farmed during the latter half of the nineteenth century when both sheep and cows were grazed.

The greater part of the existing vegetation is composed of secondary forest and scrub communities dominated by manuka (*Leptospermum scoparium*) or kanuka (*L. ericoides*). Stunted manuka scrub, where growth rates are abnormally slow, occurs on gentle slopes.

The pine plantation was established on both steep and easy rolling slopes, but stunted pines have only developed on gentle slopes coincident with areas of stunted manuka scrub. Although there is much variation within the plantation, particularly in the stunted stands, boundaries between affected and unaffected stands are usually sharply defined with the two types of growth forming a mosaic pattern of variation (Fig. 2). Logging of the millable stands has been proceeding since 1954.

MORPHOLOGY AND GROWTH OF STUNTED PINES

The degree of height and radial growth reduction is seen from the measurements given in Table 1. In many trees, death of the leader has occurred (Figs 3, 4), and accompanying stunted growth is a reduction in cone size, foliage density, and needle length. Yellowish-green foliage colorations are characteristic; individual needles are often slightly

TABLE 1.—Height and Diameter Growth of *P. radiata* at Cornwallis.

Soil type	Growth	No. of measurements	Height (ft)	Diam. breast height (in.)
Waikare silty clay	Tall	118	61 ± 16*	12·9 ± 3·9*
Cornwallis silty clay	Stunted	83	13·5 ± 7*	3 ± 2·2*

*Population standard deviation.

twisted in form and usually retained for only two years instead of three as in tall trees. Such symptoms have been described as indicative of soil nutrient deficiencies, particularly phosphate (Stoate, 1950; Weston, 1956).

FIG. 3.—Stand of stunted *P. radiata* at Cornwallis.

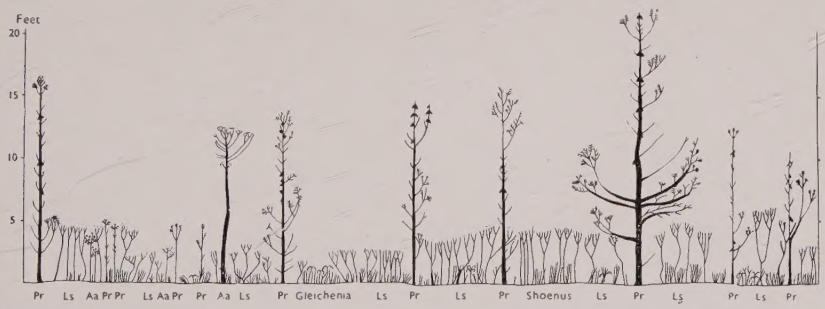

FIG. 4.—Profile diagram through stand of stunted 35-year-old *P. radiata* (Site No. 1).
Pr = *Pinus radiata*; Aa = *Agathis australis*; Ls = *Leptospermum scoparium*.

Stunted pines possess invariably a shallow poorly developed root system. Tap roots are short and rarely penetrate to depths below 12 in. Lateral roots are few in number and restricted to first and second orders of branching. No active short roots were observed. Shallow root systems on poorly drained soils suggest inferior aeration as a limiting factor although the increased growth in the more waterlogged hollows shows that no simple explanation can be found in drainage conditions alone.

An examination of the root systems of 12 extremely stunted pines (< 5 ft in height), showed that the tap roots were doubled back for distances up to 6 in. and in most cases had become fused to and enveloped by surrounding roots, giving a club-shaped appearance. This club-rooted condition, not observed among larger trees, was clearly indicative of careless planting in which the young tree had merely been thrust into a spade-cut and stamped in.

Mycorrhizal roots are either absent or extremely poorly developed with little branching; a marked contrast to tall trees where there is an extensive development of coralloid branched mycorrhizal roots. This reduced mycorrhizal development may be a result rather than a cause of stunted growth. Without adequate short-root formation mycorrhizal infection will not be possible.

Extension growth measurements showed that the stunted pines were growing at a rate approximately one-quarter than of the tall trees. This was due mainly to a difference in the absolute rate of growth but in some trees an effective shortening of the growth season resulted from a delay in extension growth initiation.

Cross-sections, from the bases of five tall pines on a moderately steep site (Site No. 5, see below) were compared with cross-sections from five stunted trees on a hummock site in rolling topography (Site No. 1). Total diameter growth plotted against time for each group of cross-sections (Fig. 5), showed that the two groups of trees were at first comparable but after a few years diverged with a progressive reduction of increments in stunted trees. During the last 12 to 15 years, increase in the diameter growth of the stunted trees has been negligible so that these trees have merely been existing.

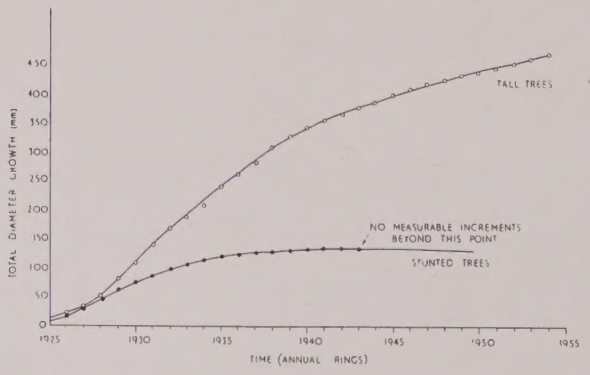

FIG. 5.—Diameter-time curves for stunted and tall *P. radiata* at Cornwallis.

The annual increments of individual stunted trees showed large fluctuations from year to year and no correlation with the rainfall figures available for Cornwallis was possible. False or double rings were frequently present in the late summer wood.

Newhook (1959) has found that the root infecting fungus *Phytopthora cinnamomi* is widespread in the Auckland area both among shelter-belts and plantations of *P. radiata*. Using their standard apple-trap technique, Dr F. J. Newhook and Mr B. Uljee tested a series of Cornwallis soil samples for the presence of *P. cinnamomi*. The results showed that in both tall stands on Waikare silty clay and stunted stands on the Cornwallis silty clay, *P. cinnamomi* was present in high concentrations, sufficient to affect pine growth (Dr F. J. Newhook, pers. comm.). Thus, even though mortality among the stunted stands has been low, fungus disease could be a contributing factor to the stunted condition. This aspect was not studied further since the correlation between differences in pine growth and soil type suggested that stunted growth was due primarily to soil properties.

RELATIONSHIP BETWEEN SOIL TYPE AND PINE GROWTH

Method

Descriptions of *P. radiata* stands and soil profiles were made on a number of contrasting sites to ascertain whether or not there was a relationship betwen soil type and pine growth. Stand classes recognized were as follows:

Tall stands: Tall trees (50 to 80 ft). Dark green foliage.

Unthrifty stands: Medium and tall trees (40 to 60 ft). General thinning of foliage in the tops and a slight yellowing of the leaves.

Stunted stands: Short trees (10 to 40 ft). Overall reduction in foliage and yellowing of leaves. Dieback of leaders.

The distribution of these stand classes is mapped in Fig. 6. Within each stand class, half square chain quadrats were laid out on flat, moderately steep, and steep sites and the following data collected from each site-stand:

(i) Height, coverage, number of surviving trees, and mean diameter breast height of *P. radiata*.

(ii) Height and composition of remaining vegetation layers.

(iii) Soil profile description. Profiles were described under both summer and winter conditions and any significant variations noted.

The sites described below are representative of the most widespread soil types in the *P. radiata* plantation at Cornwallis.

Note on Soil Type Nomenclature

The Parau soils mapped by the New Zealand Soil Bureau (1954) are a complex of brown granular clays and northern yellow-brown earths which have been renamed the Parau-Warkworth complex. The Parau is retained for the brown granular clay member of the complex,

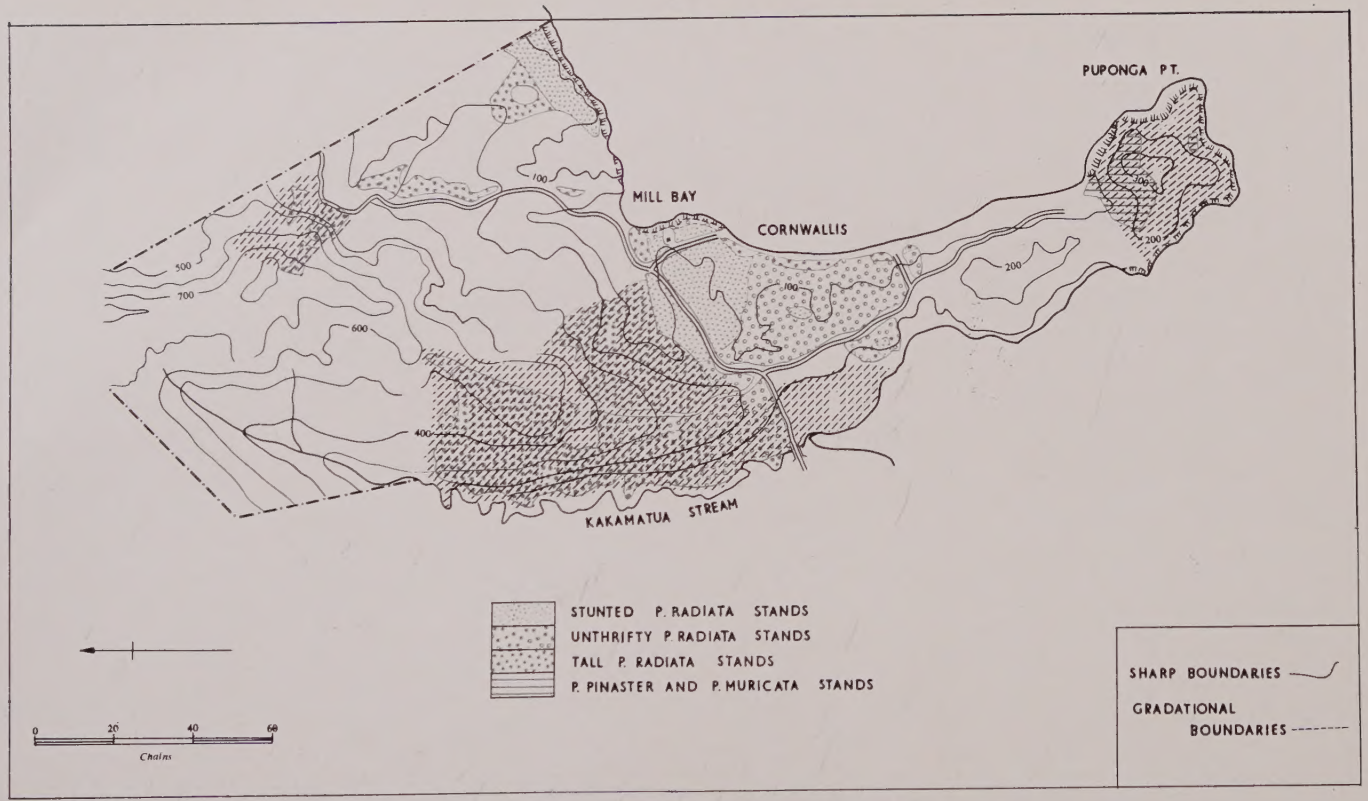

FIG. 6.—Pattern of pine growth at Cornwallis.

while the larger part of the yellow brown earths have been correlated with Warkworth. The Waikare silty clay is one of the Waikare clays (45) (*op. cit.*). Cornwallis silty clay is a new name introduced to cover the more degraded variants of the Parau clay.

Soil-Vegetation Profiles

Site No. 1

Stunted pine stand on hummock site in undulating topography. Grid ref.: 126430 (N42). Slope: < 5°. Alt.: 100 ft.

Vegetation (height ranges):
4-20 ft *P. radiata*; mean d.b.h.: 1·4 ± 7·7 in. (49 trees); coverage: 20%.
3-12 ft *Agathis australis*; coverage: 1%.
3-6 ft *Leptospermum scoparium*; coverage: 50%.
< 3 ft *Schoenus tendo* and *Gleichenia circinata*.

Soil (horizon depths):
¼ in. sparse covering of *Leptospermum, Schoenus* and *Pinus* leaves; clumps of the lichen (*Cladonia floerkiana* abundant;
9 in. dark greyish brown (10YR 4/2) clay; many distinct medium and fine red (2·5YR 4/6) mottles; tightly compact; plastic, sticky and wet for most of the year but very hard when dry; weakly developed very coarse blocky to almost massive structure when moist but becoming strongly developed very coarse blocky and very coarse prismatic structure when dry; distinct boundary;
33 in. brownish yellow (10YR 6/8) clay; very tightly compact and hard to dig; plastic, sticky, and wet; almost massive breaking to very coarse blocky structure; diffuse boundary;
10 in. brownish yellow clay as described above but with numerous red flecks and streaks; distinct boundary;
30 in. red (10R 5/6) clay;
on weak red (10R 5/2) friable clay; a weathering product of a marine-bedded, fine-grained, andesitic tuffaceous grit.

Drainage: Very poor.

Soil type: Cornwallis silty clay, rolling phase.

Stunted pine growth always occurred on this type of soil where, on hummock sites, extensive sheet erosion had taken place. In hollows and shallow gullies this soil graded into a dark grey (2·5YR 4/0) silt loam where pine growth improved, though still stunted.

Site No. 2

Unthrifty pine stand on rounded spur in rolling topography. Grid ref.: 124437 (N42). Slope: 10°. Alt.: 300 ft.

Vegetation (height ranges):
30-45 ft *P. radiata*; mean d.b.h.: 12·2 ± 5·8 in. (4 trees); coverage: 20%.
20-25 ft *Leptospermum scoparium;* coverage: 70%.
3-5 ft *Olearia rani, Geniostoma ligustrifolium, Melicytus ramiflorus, Cyathea dealbata.*

Soil (horizon depths):
½ in. *Pinus* needles, *Leptospermum* and *Melicytus* leaves;
1 in. dark brown humus with very fine crumb structure;

8 in. yellowish brown (10YR 5/4) clay; few faint fine reddish brown (2·5YR 4/4) mottles; tightly compact; weakly developed coarse blocky structure; indistinct boundary;

28 in. brownish yellow (10YR 6/8) clay; many distinct fine reddish brown mottles; tightly compact and hard to dig; moderately developed coarse nutty structure; indistinct boundary;
on red (10R 5/6) clay; a weathering product of an andesitic tuffaceous grit.

Drainage: Poor.

Soil type: Cornwallis silty clay, rolling phase.

Site No. 3

Tall pine stand on steep valley wall. Grid ref.: 114443 (N42). Slope: 30°. Aspect: W. Alt.: 300 ft.

Vegetation (height ranges):

80-100 ft *P. radiata*; mean d.b.h.: 14·3 ± 3·9 in. (19 trees); coverage: 90%.

15-20 ft *Melicytus ramiflorus, Geniostoma ligustrifolium.*

3-10 ft *Geniostoma ligustrifolium.*

Soil (horizon depths):

1½ in. *Pinus* needles;

½ in. decomposing and humified litter;

18 in. dark brown (10YR 3/4) clay; very friable; moderately developed medium nutty breaking to fine nutty structure; diffuse boundary;

18 in. strong brown (7·5YR 5/6) clay; friable; moderately developed medium and coarse nutty structure; occasional brownish yellow flecks; sharp boundary;
on red (2·5YR 4/6) weathered andesitic tuffaceous grit.

Drainage: Well drained.

Soil type: Parau hill soils.

Site No. 4

Tall pine stand on broad flat-topped ridge. Grid ref.: 136439 (N42). Slope: < 5°. Aspect: S. Alt.: 175 ft.

Vegetation (height ranges):

50-65 ft *P.radiata*; mean d.b.h.: 13·3 ± 3·7 in. (8 trees); coverage: 80%.

10-20 ft *Suttonia australis, Coprosma arborea, Melicytus ramiflorus.*

5-10 ft *Suttonia australis, Leucopogon fasciculatus, Coprosma australis.*

1-3 ft *Gahnia setifolia.*

Soil (horizon depths):

1½ in. *Pinus* needles, twigs, branches, and cones;

½ in. decomposing litter with very abundant ramifying fungal hyphae;

2 in. brown spongy humus with very fine crumb structure; abundant fungal hyphae and *Pinus* roots, sharp boundary;

6 in. dark grey (10YR 4/1) silty clay; firm; very hard when dry; strongly developed very coarse nutty breaking to medium and fine nutty structure; numerous mycorrhizal roots in cracks; distinct boundary;

12 in. dark greyish brown (10YR 4/2) clay; many distinct medium brownish yellow (10YR 6/6) mottles; firm; hard when dry; strongly developed very coarse prismatic breaking to moderately developed coarse nutty structure; indistinct boundary;
on intermingled brownish yellow (10YR 6/6) and yellowish brown (10YR 5/4) clay; compact; massive; a weathering product of interbedded feldspathic sandstones and mudstones.

Drainage: Imperfect.
Soil type: Waikare silty clay.

Site No. 5

Tall pine stand on moderately steep spur. Grid ref.: 125433 (N42). Slope: 15 to 20°. Aspect: S. Alt.: 100 ft.
Vegetation (height ranges):
60-75 ft *P. radiata*; mean d.b.h.: 16·5 ± 5·8 in. (13 trees); coverage: 80%.
10-20 ft *Melicytus ramiflorus, Suttonia australis.*
3-10 ft *Cyathea dealbata, Geniostoma ligustrifolium.*
Soil (horizon depths):
1 in. *Pinus* leaves, twigs, branches, cones, and *Melicytus* leaves;
¼ in. decomposing litter with abundant fungal hyphae;
½ in. dark brown humus with fine crumb structure;
12 in. greyish brown (10YR 5/2) clay; friable to firm; strongly developed medium and fine nutty structure, distinct boundary.
30 in. dark yellowish brown (10YR 4/4) clay; few distinct medium reddish brown (2·5YR 4/4) mottles, friable; moderately developed coarse nutty breaking to medium and fine nutty structure; sharp boundary; on yellowish brown (10YR 5/4) sandy clay with occasional lumps of plastic grey clay and yellowish brown weathered sandstone; a weathering product of feldspathic sandstones and mudstones.
Drainage: Well drained.
Soil type: Warkworth hill soils.

Small areas of *P. radiata* growth also occur on Waitakere hill soils in the northern half of the reserve. At the southern end of the peninsula (Puponga Point) an area of Awapuku hill soils occurs where a healthy plantation of *P. pinaster* and *P. muricata* has been established. Also present in this region is a small area of Red Hill sandy clay loam (Fig. 7).

Soil Type and Pine Growth Variation

Table 2 summarizes the relationships between soils and pine growth at Cornwallis; all major differences in stand growth can be correlated with soil type and geology. The mosaic pattern of pine growth (Figs 2, 6) is a reflection of the distribution of tuffaceous grit and feldspathic sandstone and mudstone rocks in the transitional passage beds between the Manukau and Waitemata formations (Fig. 7).

With increasing slope the Cornwallis silty clay passes imperceptibly into the Parau hill soils with a correlated improvement in pine growth. Within the stunted pine stands there is much variation in the degree of stunting. Variation in parent material, extensive sheet erosion, and the former presence of kauri for varying lengths of time are all factors which may have contributed to this variation but no attempt has been made to assess their relative importance in this study.

Stunted *Pinus radiata*, comparable to the stands at Cornwallis, have developed in the New Zealand Forest Service plantation at Riverhead, 20 miles to the north of Cornwallis. In this case a spectacular response

TABLE 2.—Relationship Between Soils and the Growth of *Pinus radiata* at Cornwallis.

Parent material	Slope	Soils	Genetic Classification (Taylor, 1948)	Pine Growth
Andesitic tuffs and breccias (Manukau Breccia Formation)	Moderately steep	Waitakere hill soils	Moderately to strongly leached brown granular clays	Tall
	Flat and rolling	Not present	—	—
Andesitic tuffaceous grits and tuffaceous sandstones (Waitemata Formation)	Moderately steep	Parau hill soils	Moderately to strongly leached brown granular clays. Form a complex with the Warkworth hill soils	Unthrifty to tall e.g. Site 3
	Rolling	Cornwallis silty clay, rolling phase	Strongly leached brown granular clays. Sheet eroded	Unthrifty e.g. Site 2
	Flat and undulating	Cornwallis silty clay	Strongly leached brown granular clay with gleyed A horizon. Sheet eroded	Stunted e.g. Site 1
Feldspathic sandstones and mudstones (Waitemata Formation)	Moderately steep	Warkworth hill soils	Moderately to strongly leached northern yellow-brown earths.* Form a complex with the Parau hill soils.	Tall e.g. Site 5
	Flat and rolling	Waikare silty clay	Strongly leached to weakly podsolized northern yellow-brown earth	Tall e.g. Site 4

*The name "northern yellow-brown earths" designates a group of zonal soils as mapped in "Soils", *in* "A Descriptive Atlas of New Zealand" (A. H. McLintock, Ed., 1959).

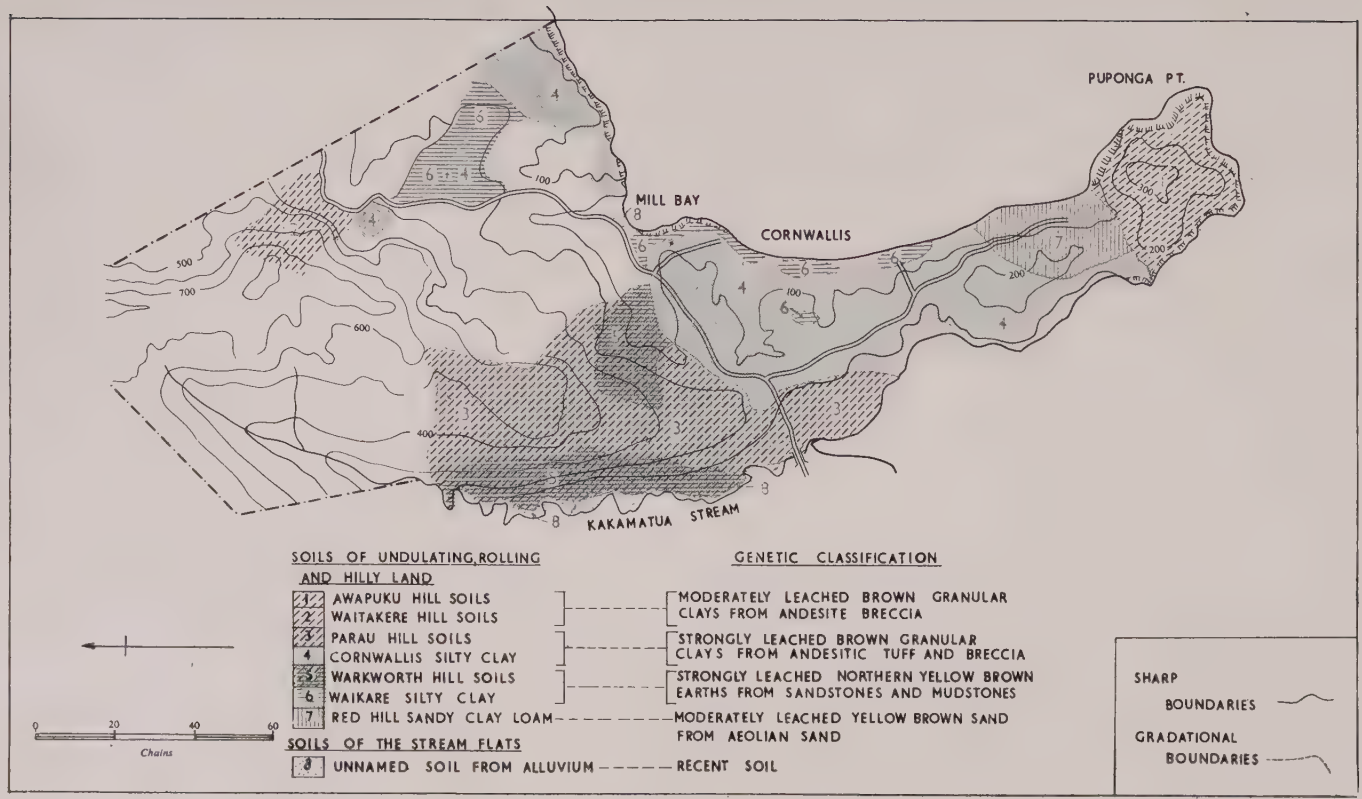
PUPONGA PT.
MILL BAY
CORNWALLIS
KAKAMATUA STREAM
SOILS OF UNDULATING, ROLLING AND HILLY LAND
1 AWAPUKU HILL SOILS
2 WAITAKERE HILL SOILS
3 PARAU HILL SOILS
4 CORNWALLIS SILTY CLAY
5 WARKWORTH HILL SOILS
6 WAIKARE SILTY CLAY
7 RED HILL SANDY CLAY LOAM
SOILS OF THE STREAM FLATS
8 UNNAMED SOIL FROM ALLUVIUM
GENETIC CLASSIFICATION
MODERATELY LEACHED BROWN GRANULAR CLAYS FROM ANDESITE BRECCIA
STRONGLY LEACHED BROWN GRANULAR CLAYS FROM ANDESITIC TUFF AND BRECCIA
STRONGLY LEACHED NORTHERN YELLOW BROWN EARTHS FROM SANDSTONES AND MUDSTONES
MODERATELY LEACHED YELLOW BROWN SAND FROM AEOLIAN SAND
RECENT SOIL
SHARP BOUNDARIES
GRADATIONAL BOUNDARIES
0 20 40 60
Chains

FIG. 7.—Soils of Cornwallis.

to aerial topdressing of superphosphate has been obtained (Weston, 1956). A similar mosaic pattern of brown granular clays and yellow brown earths occurs in this locality and it appears probable that the problem here is basically the same as that at Cornwallis

Soil Chemical Analyses

Method

Attention was focussed on a comparison of the Waikare silty clay and Cornwallis silty clay since on these soils contrasting pine stands occurred adjacent to each other on sites of similar gentle slope. Measurements were obtained from triplicate analyses of three samples of these soils collected from depths of 3 to 6 in. (Sites 1 and 4). Phosphorus analyses were made on five samples from these sites.

Soil pH was determined by using a Cambridge portable pH meter with glass-calomel electrode and following the method recommended by Metson (1956). The method of Truog (1930) was used for measurement of "available" phosphorus. Organic carbon was determined by using the Schollenberger-Allison volumetric method as modified by Metson (1956). For nitrogen determinations, a standard micro-Kjeldahl method was followed. Ammonium acetate was used as a leaching agent in the cation-exchange capacity measurements. Leachates obtained from these C.E.C. analyses were sent to the Galloway Laboratory of the Rukuhia Soil Research Station, Department of Agriculture, for determination of exchangeable bases using a Beckman flame photometer. The figures shown for exchangeable bases have been corrected using the mean values of "standard blank" determinations as suggested by Metson (1956).

Results

The soil chemical analyses are given in Table 3. Comparison of the Cornwallis silty clay with the Waikare silty clay does not reveal any marked differences in nutrient status. Both soils are strongly leached of cations, total nitrogen is low and available phosphorus very low (cf. Metson, 1956, pp. 168-175). Phosphorus concentrations in particular are likely to be limiting plant growth (cf. Davies, 1939) and the low pH and high C/N ratios indicate an environment unsuitable for microbiological activity. Nevertheless, there is no evidence from this analysis to suggest that differences in plant nutrient concentrations *per se* are responsible for the differences in pine growth.

Soil Physical Analyses

Method

Measurement of a number of physical properties known to affect mechanical impedance, available moisture and aeration conditions was

TABLE 3.—Chemical Analyses of Cornwallis Soils.

Soil Type	P_2O_5%	K_2O%	pH	Total N%	C/N	C.E.C. m.e.%	T.E.B. m.e.%	% B.S.	Exch. Ca m.e.%	Exch. Mg m.e.%
Cornwallis silty clay	0·003	0·012	4·8	0·20	27	13·4	3·7	28	1·1	2·0
Waikare silty clay	0·003	0·023	4·8	0·20	23	22·3	5·7	26	1·0	2·7

TABLE 4.—Physical Analyses of Cornwallis Soils.

Soil type	Depth (in.)	Mechanical analysis				Total porosity %	Macro-porosity (pores drained at suction of 50 cms of water) %	Apparent density	Lower plastic limit (% oven-dry wt.)	Wilting point (% total apparent vol.)
		Coarse sand %	Fine sand %	Silt %	Clay %					
Waikare silty clay	0-3	8	1	33	58	61·9	13·7*	0·95	37·2	29
	12-18	0·5	9·5	24	66	57·6	7·6**	1·1	39·6	—
Cornwallis silty clay	0-3	2	16	34	48	63·6	2·2*	0·90	50·5	32
	12-18	0·5	4·5	21	74	63·0	2·0**	0·97	54·0	—

*Least difference between these values for significance at 0·1% is 7·6.
**Least difference between these values for significance at 0·1% is 2·4.

made to establish whether or not there were significant differences between the Cornwallis silty clay and the Waikare silty clay.

The mechanical analysis was carried out using a standard pipette method. Porosity measurements were made by taking samples in cans of known volume. Atterberg's lower plastic limit (Baver, 1956, p. 109) was used as a measure of soil consistency. The tomato plant technique of Breazeale and McGeorge (1949) was used to determine wilting point percentages. The measurements recorded are the means from 5 or 6 samples from each soil type with the exception of the subsoil mechanical analyses which are based on 3 samples. Measurements of field soil moisture were made on 5 widely distributed sites for each soil type.

Results

In the physical analyses of Table 4 the major differences between the two soils are those of macro-porosity and lower plastic limits, the significance of which will be discussed subsequently in relation to other soil properties and root growth. Measurement of soil moistures in the field (Table 5) shows that both topsoils reach moisture levels below the wilting point. However, moisture levels were always found to be higher in the Cornwallis silty clay at any particular time so that available moisture cannot be responsible for the difference in pine growth.

TABLE 5.—Range of Field Soil Moisture Found at Cornwallis.

Soil type	Depth (in.)	Soil moisture as % total apparent volume		
		April-July	August-November	December-March
Waikare silty clay	4-6	30-46	25-43	16-34
	15-18	43-50	43-50	33-48
Cornwallis silty clay	4-6	47-58	29-58	23-41
	15-18	47-63	42-63	40-62

FOLIAGE ANALYSES

Leaf age, time of sampling, aspect and position in the tree crown, are known to influence foliage nutrient levels besides the concentration of nutrients in the soil (White, 1954; Tamm, 1955; Will, 1957). In this study, leaves were classified into age groups, times of sampling were synchronized, and all samples taken from the north side of the tree, three-quarters of the crown height distance below the apex. Analyses of samples from two contrasting trees were carried out by the Forest Research Institute, Rotorua. Nitrogen and phosphorus analyses were made by the writer on two bulked samples of the current season's needles collected from each of five stunted and five tall trees.

Results

Published leaf analyses of *P. radiata* are few and "critical nutrient concentrations", below which reduced growth rates are found, have not yet been established. However, it may be noted that all phosphorus levels found at Cornwallis (Tables 6, 7), are low when compared to those published by Will (1957). Single-tree comparisons are open to the criticism that there is no measure of between-tree variability in mineral concentrations. This difficulty has been partially overcome in the group comparison (Table 7) where individual differences will have been at least partially evened out in the analysis of bulked samples. In this case, early summer sampling of the current season's needles allows a comparison of differences in *current* rates of nutrient uptake without complications due to redistribution of minerals. The oven-dry weight percentages suggest that the rate of both nitrogen and phosphorus uptake is reduced in the stunted trees. These results can be expressed as total amounts of nutrient taken up per needle (Table 7), which though providing no measure of absorption by other parts of the plant, nevertheless indicates that the stunted pines have taken up, into their foliage, less than one-third the total quantity of nitrogen and phosphorus absorbed by the tall trees. The actual difference is probably greater due to the reduction in foliage density and small size of the stunted pines already noted.

FIELD TRIALS

Trace Element Spray Trials

Groups of stunted trees were sprayed with solutions of manganese sulphate (0·6%), ammonium molybdate (0·16%), and zinc sulphate (0·6 and 2·5%) using "Bliss" detergent as a wetting agent. No observable growth response was obtained.

Fertilizer Trials with Stunted Trees and Seedlings

Trials were restricted to the Cornwallis silty clay where a series of plots each containing 8 stunted trees were established with topdressings of superphosphate (10 cwt per acre), nitrate (nitrate of soda and ammonium sulphate at 4 cwt per acre), lime (15 cwt per acre), and potash ($\frac{1}{2}$ cwt per acre). A similar series of fertilizer trials using blocks of 20 one-year-old *P. radiata* seedlings was laid out in an area of disced Cornwallis silty clay. In all cases, extension growth, needle length, and foliage colour were compared with control plots of untreated plants.

Significant responses were obtained with all phosphate treatments though among the stunted trees the effect of added fertilizer was not apparent until the second growth season after topdressing. Extension

Table 6.—Single Tree Leaf Analysis of Tall and Stunted Pines at Cornwallis (5/12/55).

Tree Description	Leaf Age	% Oven-dry weight						
		Ca	Mg	K	Na	Mn	N	P
Tree No. 1. Ht.: 60 ft. D.b.h.: 20 in.	1 yr	0·12	0·16	1·07	0·07	0·03	1·53	0·072
Age: 33 yrs. Site: ridge-top.	2 yr	0·26	0·13	0·97	0·07	0·06	1·71	0·056
Soil type: Parau hill soils. Grid ref.: 443438.	3 yr	0·36	0·13	0·64	0·13	0·05	1·47	0·056
Tree No. 2. Ht.: 27 ft. D.b.h.: 6 in.	1 yr	0·09	0·15	1·12	0·09	0·02	1·14	0·055
Age: 33 yrs. Site: hummock in undulating topography.	2 yr	0·24	0·12	0·66	0·11	0·03	1·59	0·046
Soil type: Cornwallis silty clay. Grid ref.: 443432.	3 yr	0·39	0·13	0·48	0·25	0·04	1·53	0·046

Table 7.—Nitrogen and Phosphorus Contents of First Year Needles from Tall and Stunted Pines at Cornwallis (27/12/56).

Tree Description	% oven-dry weight		Fresh wt. of single needle in mgms (mean of 50 measurements)	Total mineral uptake per needle (mgms)	
	N	P		N	P
Tall trees (5) Mean ht.: 60 ft. Mean d.b.h.: 13 in. Flat site. soil type: Waikare silty clay.	1·48	0·095	58	0·86	0·055
Stunted trees (5) Mean ht.: 20 ft. Mean d.b.h.: 6 in. Flat site. Soil type: Cornwallis silty clay	0·82	0·074	21	0·17	0·016

growth and needle length were greatly increased and dark green foliage colours developed (Fig. 8).

No responses were obtained with any other treatments. Addition of litter from tall stands and trenching to improve the drainage of stunted

FIG. 8.—Stimulation of foliage growth on dead-topped *P. radiata* tree at Cornwallis following addition of phosphate fertilizer.

trees also failed to produce increased growth. A further comparison between seedlings grown on disced and those grown on undisced Cornwallis silty clay showed no differences in growth rates.

Glasshouse Experiments

Preliminary experiments confirmed that both the Waikare silty clay and Cornwallis silty clay soils were deficient in available plant nutrients. No evidence for mineral toxicity or trace element deficiencies could be found. In Experiments 1-3 an attempt was made to measure differences in plant nutrient status between these two soils under conditions where soil physical properties were not limiting. The effects of soil physical conditions on root growth were compared in Experiment 4 using undisturbed soil blocks. All soils were collected from Site 1 (Cornwallis silty clay) and Site 4 (Waikare silty clay). Experimental designs used were either Latin squares or completely randomized layouts while the statistical analysis of results followed that suggested by Cochrane and Cox (1957).

Experiment 1

Method: Using tomato plants as an indicator, a series of nutrient solutions in which one of the nutrients nitrogen, phosphorus, potassium, magnesium, and sulphur had been excluded, was added to both soils. Thus, a biological measure of differences in the availability of nutrients could be made.

Expanded perlite was mixed with both soils in a 1:2½ soil:perlite ratio to ensure that aeration and moisture conditions were not limiting. After germination in perlite, the tomato seedlings were selected for uniformity and planted three to a 4 in. diameter earthenware pot. All pots were treated with bitumastic paint to prevent differential exchange of nutrients between soil and pot and placed in petrie dishes to prevent interchange of nutrients between treatments. Nutrient solutions followed those suggested by Meyer and Anderson (1941):

(i) "Full nutrient solution"

1 M $MgSO_4 7H_2O$	2·3 ml per litre
1 M $Ca(NO_3)_2 4H_2O$	4·5 ml per litre
1 M $K H_2PO_4$	2·3 ml per litre

(ii) "Minus nitrogen solution"—the calcium nitrate was replaced by 1 M $CaCl_2$

(iii) "Minus phosphate solution"—the potassium phosphate was replaced by 1 M KCl

(iv) "Minus potassium solution"—the potassium phosphate was replaced by 1 M $NaH_2PO_4.H_2O$

(v) "Minus magnesium solution"—the magnesium sulphate was replaced by 1M Na_2SO_4

(vi) "Minus sulphate solution"—the magnesium sulphate was replaced by 1 M $MgCl_2.6H_2O$

(vii) Control—water only.

Nutrient solutions were added at the rate of 25 ml per week and growth observed over a period of 10 weeks. The experimental design was a 14×5 completely randomized block.

TABLE 8.—Comparison of Tomato Growth on Soils Treated with Various Nutrient Solutions: Experiment 1.

Treatment	Mean dry weight (g)	
	Waikare silty clay	Cornwallis silty clay
Control	2·22	2·19
"Full nutrient"	3·03	3·23
"Minus nitrogen"	2·35	2·51
"Minus phosphorus"	2·23	2·19
"Minus potassium"	3·18	3·20
"Minus magnesium"	3·17	3·16
"Minus sulphate"	3·18	3·10

Results: Mean dry weights for each treatment are shown in Table 8. The analyses of variance showed that growth was significantly increased whenever phosphorus was included in the nutrient solution. Omission of potassium, magnesium, or sulphate did not depress growth significantly but on the Cornwallis silty clay omission of nitrogen from the full nutrient solution resulted in reduced growth.

Comparison of similar treatments for the two soils showed no significant differences at the 5% level so that although phosphorus and nitrogen are deficient, there is no suggestion that differences in the levels of these nutrients can account for the differences in pine growth.

Experiment 2

Method: In order to test whether or not phosphorus or nitrogen were limiting the growth of *P. radiata*, a weighed amount of each soil (500 g) was mixed with perlite in a $2\frac{1}{2}$:1 perlite:soil ratio by volume. Seedlings were planted 3 to a 6 in. diam. pot in a 6×6 Latin square design. All replicates were inoculated with fresh humus from tall stands, nutrient solutions of phosphorus (1M KH_2PO_4) and nitrogen (1M Ca $(NO_3)_24H_4O$) added at a rate of 50 ml per week, and the experiment continued over a period of five months. At harvesting, indices of mycorrhizal root development were recorded as follows:

Root frequency	Frequency index
absent	0
few	1
many	2
abundant	3

TABLE 9.—Comparison of *P. radiata* Growth on Soils Treated with Nitrogen and Phosphorus Nutrient Solutions: Experiment 2.

Soil type	Treatment	Mycorrhizal root frequency index	Mean root dry weight (g)	Mean total dry weight (g)	t value for total dry wts.	Signficance
Waikare silty clay	nitrogen	7	2·8	7·8	3·0	* *
	phosphorus	21	4·4	10·8		
	nitrogen/ phosphorus	25	6·5	19·3	8·5	* *
Cornwallis silty clay	nitrogen	6	2·0	4·8		
	phosphorus	19	3·7	9·7	4·9	* *
	nitrogen/ phosphorus	21	5·5	15·3	5·6	* *

To reach 5% level of significance, difference between means (t) must be $> 1{\cdot}616$. To reach 1% level, difference must be $> 2{\cdot}204$.

Results: Details of treatments and results are shown in Table 9. The treatment differences indicate that both phosphorus and nitrogen are limiting on the two soils and it is evident that available phosphorus is of primary importance. Collateral experiments, not reported in detail, showed that the response observed here was not due to the cations added in the nutrient solution.

Experiment 3

Method: In order to further define the magnitude of differences in nutrient availability between the two soils, an experiment comparing perlite (3:1 perlite-soil ratio) with non-perlite treatments was made. Details of experimental design and inoculation are as recorded for the previous experiment. The plants were grown for a period of 9 months.

Results: Comparison of the two untreated soils shows slightly superior growth on the Cornwallis silty clay (treatments 1 and 2, Table 10); demonstrating that the major factors responsible for stunted growth are those associated with the Cornwallis soil in an undisturbed state. However, the improved aeration and moisture conditions of the perlite treated Cornwallis silty clay have not been accompanied by increased growth (treatments 1 and 3). It seems probable that the dilution effect of the perlite in reducing the volume of soil has reduced plant nutrient supply, particularly phosphorus, thus masking any effects which may have resulted from the improved physical conditions. With the perlite treated Waikare soil increased growth has occurred (treatments 2 and 4) which may suggest increased availability or higher concentrations of phosphorus in this soil.

TABLE 10.—Comparison of *P. radiata* Growth on Perlite and Non-Perlite Treated Soils: Experiment 3.

Tmt. No.	Soil type and treatment	Mycorrhizal root frequency index	Mean root dry weight (g)	Mean total dry weight (g)
1.	Cornwallis silty clay	19	7·8	23·3
2.	Waikare silty clay	28	5·9	18·6
3.	Cornwallis silty clay + perlite	40	7·0	22·9
4.	Waikare silty clay + perlite	35	9·2	25·9

The two perlite treatments (Nos 3 and 4) allow direct comparison of plant nutrient availability under conditions where physical factors are not limiting. This comparison based on 36 plants (2 treatments each of 6 replicates) shows that a difference in nutrient availability could account for an 11% difference in height growth and a 12% difference in total dry weight per unit volume of soil. These values are in no way comparable to the observed difference in height growth and basal area between tall and stunted pines on sites 1 and 4 in the field; here, the order of difference in height growth varied between 50 and 90%. Clearly, stunted growth must be primarily the result of soil physical conditions.

Experiment 4

Method: The following experiment was made with the aim of establishing which particular soil physical conditions were restricting root development. Undisturbed soil blocks were collected in 10 × 3 in. round cake tins. The soil surface was scraped free of organic matter and each tin pressed into the soil to its own depth, dug out, and surplus soil cut away.

In an attempt to separate the effects of mechanical impedance, available moisture and aeration, a central cylinder of soil (4 × 2 in.) was removed from one series of soil blocks and replaced with perlite. Thus, the bulk of the seedling root system would be growing in a medium where the above mentioned factors were not limiting; nutrient supply to the plant, however, would still depend on penetration of absorbing rootlets into the surrounding soil.

Within each series of perlite and non-perlite soil blocks several different moisture levels were maintained by watering the blocks to constant weight at two-day intervals. Lids with holes for the seedlings reduced water loss to a minimum. At harvesting, 10 samples for moisture content were taken from each soil block at a depth of 2 in., where most root growth was concentrated, and each treatment has ben characterized by these moisture contents.

The *P. radiata* seedlings used were germinated in perlite, selected for uniformity, and transferred to soil or perlite at the seed-leaf stage,

Table 11.—Comparison of *P. radiata* Growth on Undisturbed Soil Blocks: Experiment 4.

		Treatment No.	Moisture content (% total apparent volume)	Mean total dry weight (g)	Mean root dry weight (g)	Total No. of primary roots penetrating soil or perlite-soil interface	Total No. of mycorrhizal roots	Mean height growth (mm)
Non-perlite treatments	Cornwallis silty clay	K1	56	0·77	0·23	59	3	63
		K2	52					
		K3	52	0·47	0·17	32	56	58
		K4	50					
		K5	46	0·36	0·14	19	39	50
		K6	44					
		K7	42	0·33	0·14	16	7	51
		K8	36					
	Waikare silty clay	W1	49	2·80	0·59	33	39	131
		W2	42					
		W3	37	3·98	1·48	36	∞*	145
		W4	27					

Perlite treatments								
Cornwallis silty clay	pK1	63	0·60	0·29	45	26	57	
	pK2	55						
	pK3	47	0·54	0·24	26	32	64	
	pK4	43						
	pK5	41	0·53	0·27	18	23	49	
	pK6	30						
	pK7	29	0·63	0·30	17	46	60	
	pK8	27						
Waikare silty clay	pW1	48	1·76	0·44	23	9	114	
	pW2	45						
	pW3	20	1·07	0·66	20	25	81	
	pW4	19						
	pW5	18	2·46	1·31	14	46	93	
	pW6	16						

*Root frequency was so high that counting was impracticable.

three seedlings to a tin. All treatments were inoculated as in previous experiments, the positions of all tins randomized and re-randomized at weekly intervals, and growth observed over a period of 14 weeks.

Results: Replication of treatments at particular moisture levels was not found possible so that a statistical analysis of the results was not attempted. However, many differences were clear-cut and these can be seen in Table 11 where treatments have been grouped in pairs and arranged in descending order of moisture level.

All plants in the Cornwallis silty clay treatments developed yellowish foliage, shortened needles, and showed slow growth rates (Figs 9, 10); a marked contrast to the dark green foliage, long needles, and relatively rapid growth of the Waikare plants. Mean height growth for the two groups of treatments differed by a factor of more than 60%, a difference comparable to that observed in the field. Differences in dry weights were still more marked in both perlite and non-perlite treatments.

In the higher moisture treatments of the Cornwallis silty clay, development of structural joints and cracks was negligible. Among the remaining treatments, joints and cracks between aggregates were better developed and in these cases roots were always restricted to such cracks. In the non-perlite treatments mycorrhizal roots were restricted to the larger soil cracks (0·5 to 1 mm in width) while in the perlite treatments such roots only developed within the perlite where they were concentrated at the perlite-soil interface.

Discussion and Conclusions

Five independent lines of evidence (viz. soil and foliage analyses, field trials with adult and seedling plants, and glasshouse experiments), suggest that phosphorus is the plant nutrient of primary importance in limiting pine growth on the Cornwallis silty clay. However, both soil analyses and the results from Experiments 1-3 show that only a small percentage of the difference in pine growth between this soil and the Waikare silty clay can be accounted for by differences in concentration and "availability" of phosphorus. Thus, the reduced phosphorus uptake of the stunted pines must be attributed to soil physical conditions restricting root growth or absorption.

On a soil of low nutrient status, any physical properties which reduce root volume and surface area may be expected to reduce the total uptake of all nutrients, and in particular those, such as phosphorus, which are of low mobility. The apparent dilution effect of plant nutrients by perlite in Experiment 3 emphasises this importance of the area of absorbing roots in contact with soil. Both field observations and the results of Experiment 4 show that in the Cornwallis silty clay the volume and surface area of root growth is very greatly reduced. The restriction of root growth to structural joints and cracks between aggregates (cf. Experiment 4) and the contrast in degree of structure

FIG. 9.—Growth of *P. radiata* seedlings on undisturbed blocks of Cornwallis silty clay (left pair of treatments) and Waikare silty clay after 3½ months (see Expt. 4). Moisture contents of treatments from left to right are 52%, 36%, 49%, and 27%.

FIG. 10.—Root system of *P. radiata* seedlings grown in Cornwallis silty clay at 52% (left pai rof seedlings) and 36% (right pair) in Expt .4. Note absence of mycorrhizal roots in the moister treatment.

development on the two soils (cf. sites 1 and 4) is clearly of the highest significance. Baver (1949) has stressed the importance of large pores in affecting drainage and aeration. The macro-porosity results (Table 4) explain the contrasting drainage properties of the two soils and indicate that the overall aeration status of the Cornwallis silty clay is inferior to that of the Waikare soil.

The most important physical conditions likely to restrict root development to joints and cracks are in this case, aeration, mechanical impedance, and available moisture conditions within aggregates. In both perlite and non-perlite treatments of Experiment 4 stunted growth occurred at the highest moisture levels obtained on the Cornwallis silty clay where soil moisture could not have been a limiting factor (see Table 11). In the field it is apparent that in both soils hard consistency of aggregates during dry periods is likely to prevent penetration by roots and the decreased number of primary roots penetrating the soil or perlite-soil interface at lower moisture levels in Experiment 4 (Table 11) also suggests that mechanical impedance to root growth can be a limiting factor. However, root development is restricted in all Cornwallis silty clay treatments and it seems probable that this is primarily a result of inferior soil aeration since mechanical impedance is unlikely to be so important at the higher moisture levels. Apparently, in the perlite series of soil blocks, translocation of oxygen through the root system from the perlite has been inadequate for root growth in the soil. This suggests that aeration at the absorbing surface of the root is of critical importance.

An effect of aeration on mycorrhizal development is indicated by the increased number of mycorrhizal roots in the perlite treatments of Experiments 3 and 4 and the reduced number at the highest moisture contents of the latter experiment. High soil moisture contents maintaining inferior aeration conditions in the Cornwallis silty clay (Table 5), may well account for the poor development of mycorrhizal roots observed in the field. Morrison (1957) has demonstrated that in *P. radiata* such roots are more effective than non-mycorrhizal roots in the absorption of phosphorus; this poor development of mycorrhizal roots is thus likely to be a significant factor in reducing the uptake of phosphorus.

Further experimental evidence is required before a thorough analysis of the effects of soil physical conditions on root growth of *P. radiata* at Cornwallis can be made. Nevertheless, the experimental results do allow some understanding of the development of stunted growth to be reached. At the beginning of the growth season soil moisture is high and soil consistency allows penetration by roots. Inferior aeration, however, associated with the high moisture levels, retards root growth; no mycorrhizal roots are formed which still further limits the uptake of phosphorus, and a stunted growth form develops. During summer droughts, large vertical cracks develop which increase aeration but hard consistency of aggregates prevents root penetration. Following the first rain after a drought, topsoil moisture rises rapidly and root growth

proceeds until filling of cracks with water and subsequent expansion of aggregates crushes the new roots formed. Rainfall distribution controls the length of the autumn period when rising moisture contents are allowing root growth whilst simultaneously reducing aeration. It is probable that the length of this period is critical in determining the amount of root surface area available for the uptake of phosphorus in the folowing growth season.

Thus, stunted growth, evidently the result of phosphorus starvation, is brought about primarily by inferior soil aeration restricting the growth of absorbing roots. The soil property of greatest importance in determining these conditions is the low macro-porosity resulting from poor aggregation and weak development of structure. The fundamental distinction between the Cornwallis and Waikare soils lies in this difference in degree of structure development.

The field trials with seedlings showed that cultivation alone has no permanent effect in improving soil structure. Addition of phosphate fertilizer is necessary if pine growth is to be increased.

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SOME CORRELATIONS IN REPLICATE PLANKTON SAMPLES

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Summary

Two plankton samples were taken with a centrifugal pump from the dock wharf, Wellington, on 23 March and 5 April 1956. Each sample consisted of 50 subsamples of 200 litres volume from a depth of 1 metre. Tidal movement was such that the effective distance between subsamples was approximately 5 to 10 metres. Numerical correlations between species counts, and autocorrelations within species were examined and subjected to multiple regression analysis. A marked difference in the pattern of distribution was found between the two samples. In sample 1 variance was low, dispersion was similar for all species, interspecific correlation was low, and autocorrelation was absent. In sample 2 variance was higher, dispersion was heterogeneous, and autocorrelation was present. Only one pair of species, *Temora turbinata* and *Acartia clausii*, was correlated in both samples. Correlation between species may be due to direct biological attraction or to a common reaction to external factors. The second explanation seems preferable and further investigation of the influence of physical factors is desirable. Departure from randomness in distribution can be partly or wholly accounted for in some species by regression on other species, but the causal factors are as yet unkown. The pattern of newly laid teleostean eggs is consistent with a simple process of random diffusion from a central point of deposition.

Introduction

In a previous communication (Cassie, 1958) a technique has been described by which a series of plankton samples, each representing a known and constant volume of water, may be taken with a centrifugal pump fitted with filters which may be changed at brief intervals. In practice samples have been 200 litres at 1 min. intervals. This apparatus was designed for tracing the relationship over relatively short distances (100 metres or less between samples) between changing numerical abundance of plankton and variations in physical properties of the water. Some correlations of species to temperature and salinity, and to other species, have already been noted using a 100 metre spacing (Cassie, 1959).

The data to be discussed here were collected at an early stage of these investigations when the temperature and salinity recording equipment was not considered entirely reliable. However, the plankton by themselves present some interesting relationships which shed new light on the phenomenon of plankton aggregation, particularly since the sample spacing in this case (< 10 metres) is of an order smaller than in the work cited above.

The non-random distribution of plankton organisms in replicate samples has received considerable attention in the literature, but has been treated largely as a problem in sampling error. Less attention has

been paid to the relationships both within and between the various species represented in the samples. Winsor and Clarke (1940) noted the tendency for different plankton species in the same set of samples to have a similar variability and concluded that "irregularities in distribution (e.g. local swarming) are essentially alike for all groups". However, no attempt was made to detect correlation between species counts, probably because there was uncertainty as to how much of the departure from randomness was intrinsic to the plankton population, and how much was due to variations in the filtering power of the plankton net. Obviously if a different volume of water was filtered for each sample, a positive correlation between species counts would result, but would have no biological significance. More recently Tonolli (1958) has drawn attention to the tendency for different species of freshwater plankton to follow a similar pattern of variation in space. Within any one species he has also shown a significant correlation between adjacent samples in a continuous series (autocorrelation).

Sampling Procedure

The two samples to be discussed were taken from the north-east corner of the "Dock" wharf immediately adjacent to the floating dock in Lambton Harbour, Port Nicholson (Wellington Harbour), on the 23 March and 5 April 1956. The hose intake was lowered to 1 metre below the surface, and on each occasion 50 subsamples of 200 litres (2 discarded in first sample) were taken at 1 min. intervals. In the first sample, filters were of No. 6 xx bolting cloth (mean linear aperture 0·2 mm), in the second No. 12 xx (mean linear aperture 0·11 mm). Mesh size would have no effect on the numbers of the zooplankton species considered, but only the finer filter would be capable of holding the diatom, *Coscinodiscus*. However, a separate subsample taken with a 12 xx filter at the same time as the first sample did not show any *Coscinodiscus*, which may therefore be assumed to have been absent at that time.

The weather at the time of sampling was on both occasions calm and clear and only a slight tidal stream was flowing. Although exact current measurements were not made, floating objects thrown into the water drifted away at a rate between 5 and 10 metres a minute, so that the spatial interval represented by each sample may be regarded as 10 metres or less.

Results

Only those species will be considered which have a mean number of 2 or more per subsample in at least one of the samples. The following 3 copepod species are recorded in both samples:

Temora turbinata (Dana)
Acartia clausii Giesbrecht
Oithona similis Claus

For the second sample only, two further species were recorded:

Coscinodiscus centralis Ehrenberg
Teleostean eggs (unidentified)

All eggs were of the same species, in a similar stage of development, about five hours old.

TABLE 1.—Means, Variances, and Coefficients of Dispersion.

	Sample 1				Sample 2			
	$\bar{x}$	s^2	c	d	$\bar{x}$	s^2	c	d
T (*Temora*)	2·83	4·70	0·23	0·40	0·74	1·87	2·06	0·60
A (*Acartia*)	7·17	15·42	0·16	0·54	5·42	40·94	1·21	0·87
O (*Oithona*)	5·30	12·57	0·25	0·58	148	1141	0·045	0·87
C (*Coscinodiscus*)					775	76753	0·13	0·990
E (Teleost eggs)					3·56	90·65	6·87	0·90

Table 1 is a summary of the means, $\bar{x}$, and the variances, s^2, of these five species, together with the measures of dispersion, c and d, where:

$$c = (s^2 - \bar{x})/\bar{x}^2$$
$$d = (s^2 - \bar{x})/s^2$$

Both of these statistics have previously been discussed in more detail (Cassie, 1959). c gives a relative measure of the departure of the distribution from random, while d indicates the proportion of the variance which is in excess of random expectation. In all cases the variance is very significantly greater than the mean, indicating a greater variability than would be expected by chance alone (i.e. for a Poisson distribution). This fact (also reflected by the positive value of c), indicates that the distribution may be classed as overdispersed. In sample 1, c is relatively stable for all species, possibly because the mean numbers are very similar. In sample 2, however, c has a wide range of values which do not agree at all closely with those for the corresponding species in the first samples, even for *Acartia*, where the means are roughly similar. It is noteworthy that d is consistently lower ($< 0{\cdot}60$) for sample 1 than for sample 2 ($> 0{\cdot}60$), indicating that the variance in excess of random expectation is greater in the second sample.

INTERSPECIFIC CORRELATIONS

Total correlations between species counts are shown in Table 2. In this this and following tables and equations, each species is indicated by the first letter of its generic same. Significance levels of correlation and regression coefficients are indicated by asterisks, thus: *, $P < 0{\cdot}05$; **, $P < 0{\cdot}01$; ***, $P < 0{\cdot}001$. A dagger (†) is used in a few cases

which do not quite reach the 0·05 level, but nevertheless seem to warrant consideration. Teleost eggs are omitted from the table, since they do not show any correlation with the other species, and are a relatively transient feature of the plankton population.

TABLE 2.—Total Correlation Coefficients.

	Sample 1			Sample 2		
	A	*O*		*A*	*O*	*C*
T	0·48***	0·46***	*T*	0·74***	0·10	0·50***
A	—	0·54***	*A*	—	−0·03	0·15
			O	—	—	0·30*

In sample 1, all 3 copepod species are positively correlated to each other, while in sample 2, *Temora* and *Acartia* are the only copepods correlated. *Oithona* appears to be independent of the other copepods, though correlated to *Coscinodiscus*, which was not present in sample 1. From Tables 1 and 2 a multiple regression equation may be derived for each species, describing its apparent dependence on other species in the sample:

Sample 1:

$$\hat{T} = 0{\cdot}62 + 0{\cdot}18^{*}A + 0{\cdot}17\dagger O \qquad R^2 = 0{\cdot}29 \quad \ldots\ldots (1)$$

$$\hat{A} = 3{\cdot}3 + 0{\cdot}54^{*}T + 0{\cdot}45^{***}O \qquad R^2 = 0{\cdot}36 \quad \ldots\ldots (2)$$

$$\hat{O} = 1{\cdot}7 + 0{\cdot}38^{***}A + 0{\cdot}42\dagger T \qquad R^2 = 0{\cdot}36 \quad \ldots\ldots (3)$$

Sample 2:

$$\hat{T} = -1{\cdot}6 + 0{\cdot}14^{***}A + 0{\cdot}0020^{***}C \qquad R^2 = 0{\cdot}70 \quad \ldots\ldots (4)$$

$$\hat{A} = 7{\cdot}7 + 4{\cdot}1^{***}T - 0{\cdot}0068^{**}C \qquad R^2 = 0{\cdot}61 \quad \ldots\ldots (5)$$

$$\hat{O} = 120 + 0{\cdot}037^{*}C \qquad R^2 = 0{\cdot}09 \quad \ldots\ldots (6)$$

$$\hat{C} = 520 + 170^{***}T - 21^{*}A + 1{\cdot}7\dagger O \qquad R^2 = 0{\cdot}41 \quad \ldots\ldots (7)$$

The *Temora*:*Acartia* association is still apparent in both samples, but *Temora*:*Oithona* does not quite reach significance at the ($P = 0{\cdot}05$) level in sample 1. There is still a discrepancy between the copepod relationships for the two samples, in that *Acartia* and *Oithona* have a partial correlation only in sample 1. *Coscinodiscus* appears now to be in some degree associated with all three copepods, although the partial regression on *Oithona* does not quite reach significance. If this species is eliminated, equation 7 becomes:

$$\hat{C} = 760 + 170^{***}T - 21^{**}A \qquad R^2 = 0{\cdot}36 \quad \ldots\ldots (8)$$

Alternatively, *Acartia* may be eliminated:

$$\hat{C} = 400 + 96^{***}T + 2{\cdot}1^{*}O \qquad R^2 = 0{\cdot}31 \ldots\ldots\ldots (9)$$

The negative relationship between *Acartia* and *Coscinodiscus* (Equations 5, 7, and 8) is of some interest. Although there is no *a priori* reason why interspecific correlation should be positive, this is the first case in this and other investigations by the author where an inverse relationship has appeared. It will, however, be noted in a later section that this particular partial correlation becomes insignificant when considered in conjunction with autocorrelation.

Observations by Barnes and Hasle (1957) have some relevant features, which may be compared to those above, in that they show both a negative correlation and a change of correlation with time. In a closely spaced pattern of samples in Oslo Fiord the dinoflagellates *Ceratium fusus* and *Prorcentrum micans* were at first found to be inversely related ($r = -0{\cdot}73$), but within 8 days the sign was reversed ($r = 0{\cdot}76$).

Each of the partial regression equations is followed by the appropriate value of R^2, the square of the multiple correlation coefficient for that equation. This is a measure of the proportion of the variance of the species which may be attributed to regression on other species. R^2 is thus roughly comparable with d (Table 1) which estimates the proportion of variance in excess of random expectation. It is noteworthy that for *Temora* and *Acartia* both R^2 and d are larger for sample 2 than for sample 1, suggesting that the same causal agencies inducing overdispersion are also responsible for interspecific correlation.

Since some portion of the sample variance has been accounted for by regression, it is of interest to note whether the residual variance is still in excess of Poisson expectation. The usual test of significance where overdispersion is suspected is made from the χ^2 distribution, where:

$$\chi^2 = \Sigma x^2/\bar{x}, \quad n-1 \text{ degrees of freedom}$$
$$(\Sigma x^2 = (n-1)s^2 = \text{sum of squares of deviations from the mean, } \bar{x}.$$
$$n = \text{number of subsamples}).$$

Σx^2 may be partitioned into two components, $R^2\Sigma x^2$ which is attributable to regression, with $m - 1$ degrees of freedom (m = number of variates in the regression), and a residual $(1 - R^2)\Sigma x^2$ with $n - m$ degrees of freedom. The appropriate test for randomness of the residual is then:

$$\chi^2 = (1 - R^2)\Sigma x^2/\bar{x}, \quad n - \text{m degrees of freedom.}$$

These two tests are made for *Temora* in Table 3. For each example, the first χ^2 is very highly significant, showing that there is virtually no probability of the distribution having arisen by chance. After subtracting the regression component, the second χ^2 is well within the

($P = 0{\cdot}05$) confidence limits, suggesting that *Temora* might have been randomly distributed but for some external factor which is made manifest by the interspecific correlation. This result must perhaps be accepted with some reserve, since *Temora* is the least abundant species and thus less likely to reveal overdispersion. For the remaining species the test is less successful, although for *Acartia* (sample 1), after elimination of regression variance, $P(\chi^2) = 0{\cdot}03$, a relatively low significance level.

TABLE 3.—Effect of Regression on Departure from Random Distribution in *Temora*.

Sample 1 $\bar{x} = 2{\cdot}8333$	$R^2 = 0{\cdot}2872$			
	Sum of squares	Degrees of freedom	χ^2	P
Total	220·67	47	77·88***	0·0006
Deviations due to regression (220·67 × 0·2872)	63·38	2		
	157·29	45	55·51	0·14
Sample 2 $\bar{x} = 0{\cdot}7400$	$R^2 = 0{\cdot}6985$			
	Sum of squares	Degrees of freedom	χ^2	P
Total	91·62	49	123·81***	$< 0{\cdot}0001$
Deviations due to regression (91·62 × 0·6985)	27·62	2		
Deviations independent of regression	64·00	47	37·33	0·82

INTRASPECIFIC CORRELATION

Just as one species may be correlated with another, so the numbers of individuals of one species in one subsample may be correlated with the numbers of the same species in adjacent subsamples, one or more spaces removed. Such interspecific correlation (or autocorrelation) indicates that dense or sparse sections of the plankton population tend to extend through more than one subsample, and may be expressed in the form of an autoregression equation:

$$\hat{X}_i = a + b_1 X_{i+1} + b_2 X_{i+2} + \ldots \qquad \ldots\ldots\ldots (10)$$

where X_i is the predicted number of individuals in the 1 th subsample, X_{i+1}, X_{i+2}, etc. are numbers in the $(i+1)$th, $(i+2)$th, etc. subsample, a is a constant; b_1, b_2, etc .are partial autoregression coefficients. Autocorrelation was completely absent in sample 1, but was strongly marked in 4 of the 5 species in sample 2. Just as with the interspecific correlations, this appears to be related to the higher level of overdispersion in the second sample and suggests that some additional disturb-

ing agency is responsible for the increased heterogeneity. The appropriate autoregression equations for the four species are as follows:

$$\hat{T}_i = 0{\cdot}25 + 0{\cdot}33^{**}T_{i+1} + 0{\cdot}33^{**}T_{i+2} \quad R^2 = 0{\cdot}34 \quad \text{..... (11)}$$

$$\hat{A}_i = 2{\cdot}49 + 0{\cdot}54^{***}A_{i+1} \quad R^2 = 0{\cdot}34 \quad \text{..... (12)}$$

$$\hat{C}_i = 250 + 0{\cdot}43^{***}C_{i+1} \quad R^2 = 0{\cdot}18 \quad \text{..... (13)}$$

$$\hat{E}_i = 0{\cdot}71 + 0{\cdot}43^{**}E_{i+1} + 0{\cdot}37^{*}E_{i+2} \quad R^2 = 0{\cdot}55 \quad \text{..... (14)}$$

Between the first three species, R^2 does not vary greatly, although autocorrelation seems to be somewhat broader in its influence for *Temora,* as witness the two partial autocorrelation coefficients. For the teleostean eggs, R^2 is appreciably higher. Since a comparatively simple explanation can be advanced to explain this particular distribution, the eggs will be discussed first.

TABLE 4.—Teleost Egg Counts.

Subsamples	Number of eggs
1-5	0
6-10	1
11-15	5
16-20	8
21-25	2
26-30	44
31-35	122
36-40	123
41-45	30
46-50	13
Total	348

Table 4 gives a condensed record of egg numbers, the subsamples being pooled in groups of 5, thus smoothing out minor irregularities. The table incidentally gives a good illustration of the nature of autocorrelation. Each figure in the second column is closer in value to one or both of its nearest neighbours than to any other figure in the distribution. Clearly the numbers form a large aggregation with a principal mode at about the 36th sample, and a very much less prominent mode at about the 16th sample. Omitting the first 14 individuals (subsamples 1-20) which compose the smaller mode, the distribution conforms approximately to a Gaussian (normal) curve. This form has been shown by Vollenweider (1956) to be generated in his "type I" mechanism of plankton aggregation, where the "swarm" (aggregation) "is centrally stimulated". This model is analogous to the physical process of diffusion of particles by random walk from a central point.

Obviously the central stimulus in this instance was supplied by an individual fish (or perhaps a small compact school of fish) which laid the eggs at a central point a few hours previously. The subsequent dispersal of the eggs from this point would produce a distribution which, though not Poisson, would be quite properly described as being generated by random agencies. Exact agreement with the Gaussian form is hardly to be expected since various simple agencies would be capable of disturbing the pattern. Change of location of the parent fish during the liberation of eggs might produce a polymodal or a skew distribution, while heterogeneity in the rate of dispersal of the eggs (due perhaps to variations in size or buoyancy) would result in kurtosis.

The remaining autocorrelations are best discussed in conjunction with the interspecific correlations.

COMBINED ANALYSIS OF INTER- AND INTRA-SPECIFIC CORRELATIONS

(See also Appendix)

It has been demonstrated (Cassie, 1959) that neither inter- nor intra-specific correlation is necessarily attributable to any direct biological interaction between or within species. For instance, the copepod *Paracalanus parvus* exhibited a pronounced autocorrelation which could be accounted for entirely in terms of discontinuities in the external environment. While pertinent physical data are not available in the present instance, it is of interest to discover whether inter- and intra-specific correlations retain their identity when incorporated in a common multiple regression analysis.

For this purpose, the data from sample 2 have been assembled in two series for each species. In *Temora* (for example) the series are:

$$\text{Series } T_i: \quad T_1, T_2, T_3, \ldots . T_{49}$$
$$\text{Series } T_{i+1}: \quad T_2, T_3, T_4, \ldots . T_{50}$$

where T_1, T_2, etc. are the subsample counts in order of occurrence. Omitting the teleost eggs, which have an independent pattern of their own, there is thus a total of 8 series. These may be paired in 28 different combinations, for each of which the correlation coefficient is shown in Table 5. From this table may be derived a multiple regression equation for each species (omitting *Oithona* which has no autocorrelation).

$$\hat{T}_i = -1{\cdot}4 + 0{\cdot}11^{***}A_i + 0{\cdot}0017^{***}C_i + 0{\cdot}45^{***}T_{i+1} \qquad R^2 = 0{\cdot}73 \quad \ldots\ldots\ldots \quad (15)$$

$$\hat{A}_i = 1{\cdot}2 + 3{\cdot}0^{**}T_i + 20{\cdot}3^{*}A_{i+1} \qquad R^2 = 0{\cdot}64 \quad \ldots\ldots\ldots \quad (16)$$

$$\hat{C}_i = 96 + 66^{**}T_i + 2{\cdot}0^{*}O_i + 0{\cdot}42^{***}C_{i+1} \qquad R^2 = 0{\cdot}50 \quad \ldots\ldots\ldots \quad (17)$$

TABLE 5.—Means, Variances, and Total Correlation Coefficients for Combined Inter- and Intra-specific Multiple Regression Analysis.

	T_i	A_i	O_i	C_i	T_{i+1}	A_{i+1}	O_{i+1}	C_{i+1}
$\bar{x}$	0·72	5·06	145	748	0·60	4·62	146	750
s^2	1·06	39·2	116	72500	1·10	16·8	116	74700
T_i	—	0·78***	0·10	0·52***	0·55***	0·49***	0·15	0·36*
A_i	—	—	0·04	0·41**	0·46***	0·54***	— 0·03	0·42**
O_i	—	—	—	0·31*	— 0·03	— 0·18	0·04	0·06
C_i	—	—	—	—	0·44**	0·34*	0·21	0·57***
T_{i+1}	—	—	—	—	—	0·51***	0·32*	0·46***
A_{i+1}	—	—	—	—	—	—	0·02	0·44**
O_{i+1}	—	—	—	—	—	—	—	0·37**

It will be seen that only one of the previous regression relationships is lost in the combined analysis, viz. the negative correlation between *Acartia* and *Coscinodiscus*. All the remaining regression coefficients retain their identity even though slightly reduced in magnitude. In Table 6 the values of R^2 from the appropriate equations are tabulated for interspecific, intraspecific, and combined regression. In spite of the independence of the two types of relationship, the gain in information through combining the two is only slight. In every case R^2 (inter-specific) is only slightly smaller than R^2 (combined). Thus, it would seem likely that both inter- and intra-specific regressions are manifestations of the same causal agency and that the incorporation of auto-correlation into the analysis has made a negligible contribution to the reduction of the excess variance.

TABLE 6.—Values of R^2 for Inter-specific, Intra-specific, and Combined Regressions.

Species	Inter-specific	Intra-specific	Combined
Temora	0·70	0·34	0·73
Acartia	0·61	0·29	0·64
Coscinodiscus	0·31-0·41	0·18	0·50

DISCUSSION AND CONCLUSIONS

In the two samples two distinct types of population pattern are found, even though the samples were taken under similar conditions, little more than a week apart in time. In the first, excess variance is low and the dispersion of all species is similar. Inter-specific correlation is low and autoregression absent. In the second, excess variance is higher and dispersion heterogeneous. Inter-specific correlations are high and auto-regression is present.

Three conclusions may be drawn. While the evidence presented will apply only to the particular conditions of this experiment, the conclu-

sions may be expressed in the form of hypotheses which will be applicable to other plankton populations. These will be appropriate primarily but not necessarily exclusively to the particular scale of distribution which has been studied here (i.e. < 10 metres sample spacing).

(a) In a plankton population, two or more species may have a common factor or factors influencing their distribution. In the present experiment these factors commonly operate in the same direction (i.e. correlation is positive), even for widely different taxonomic groups, but the possibility of inverse relationships cannot be excluded.

(b) Within any one species, numerical abundance in one region (as represented by a subsample) may not be entirely independent of the abundance in adjacent regions. Here again there is evidence of a common factor, in this case common to contiguous parcels of space. The causal agency is not necessarily a different one from that operating in (a) above.

(c) Neither of the above phenomena is necessarily intrinsic to the species concerned and independent of the environment, since the same species may exhibit different relationships at different times.

It is not possible to decide *a priori* whether the origin of a correlation between two numerical quantities A and B is internal (due to direct influence of A on B or vice-versa) or external (due to the influence of a third factor X on both A and B). In the present case the evidence seems to be slightly in favour of an external origin, since the only relationship which remains unchanged between the two samples is the *Temora*:*Acartia* correlation. Possible external factors may be arbitrarily classified as biological, bio-chemical, or physico-chemical. The only known biological change is represented by the introduction of *Coscinodiscus*, but there are obviously other possibilities, particularly among the microflagellates and bacteria which were not sampled. Bio-chemical factors would include ectocrines, antibiotics, and other metabolites, as well as the O_2:CO_2 balance which is largely a manifestation of the relative rates of respiration and photosynthesis. Among the physical factors, temperature and salinity rank high in biological significance. Although neither was accurately known for this experiment, the variability of these two factors did not appear to be sufficient to account for the observed aggregation pattern. Obviously this classification of factors is somewhat artificial. For instance, the "biological" influence of one species on another may be affected by the medium of a "bio-chemical" metabolite.

It is of some interest to note that variance attributable to inter-specific regression may on occasion be of sufficient magnitude to account for over-dispersion, even if the actual causal relationship is unknown. If two species A and B are both correlated to an external factor (or complex of factors), X, they will themselves be correlated. If there is

no partial correlation between A and B independent of X, it may be shown that the following relationship will exist:

$$r_{AB} = r_{AX}\, r_{BX}$$

where r_{AB}, etc. are the total correlation coefficients of A to B, etc. If the sign is disregarded, a correlation coefficient cannot, by definition, exceed unity. Since in natural phenomena of this type a random element is invariably present, all coefficients will in practice be less than unity, so that from the above equation r_{AB} will always be smaller than r_{AX} or r_{BX}. It will, then, be expected that the external causal agency, if it can be isolated, will account for an even greater proportion of the excess variance than the inter-specific correlations.

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APPENDIX

NOTE ON COMPUTATION OF AUTOREGRESSION

Since the present interest is more in levels of significance than in precise estimation of parameters, certain approximations have been made in the computation of equations involving autoregression (11-17).

Although subsamples are, for computation purposes, arranged in the order in which they are taken, they are not essentially a time series, so that subsamples X_i is just as likely to be correlated to subsample X_{i+1}

as to subsample X_{i-1}. Strictly speaking then, the general form of the autoregression equation (10) should be:

$$\hat{X}_i = a + b_1 X_{i+1} + b_{-1} X_{i-1} + b_2 X_{i+2} + b_{-2} X_{i-2} + \ldots . \quad (18)$$

In an infinite series, the regression coefficients, b_1, b_2, etc. will be equal to their respective counterparts, b_{-1}, b_{-2}, etc., so that equation (19) becomes:

$$\hat{X}_i = a + b_1 X_{i\pm 1} + b_2 X_{i+2} + \ldots . \quad (19)$$

Since the present series is finite, regression coefficients in equation (10) will not be identical to those in equation (19) although for present purposes they will be adequate.

This simplification becomes of some importance in computing the more complex combined regression equations (15-17). Using the statistics in Table 5, two equations can be derived for each species, with $\hat{X}_i$ and $\hat{X}_{i+1}$ respectively as the independent variates. Only the first of these equations has been computed.

A further approximation has been made in incorporating equation (11) (*Temora*) in the combined analysis. Although there are two significant autoregression coefficients, only one autocorrelation coefficient has been computed in Table 5. R^2 is thus reduced from 0·34 to 0·25, a loss of information of about a quarter.

PHOTOGRAPHS OF THE BOTTOM FAUNA IN THE ROSS SEA

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Summary

Photographs of the sea bed in the vicinity of McMurdo Sound, Antarctica, are presented. The photographs show four different bottom faunas dominated by:

(1) Gorgonacea, Polyzoa, and Porifera.

(2) A species of Lamellibranchiata and a species of Asteroidea.

(3) Porifera.

(4) Polyzoa, Polychaeta, and Ophiuroidea.

Filter-feeding organisms are abundant in these bottom faunas.

Introduction

An oceanographic survey of the Ross Sea was carried out in the summer of 1958-59 from H.M.N.Z.S. *Endeavour*. Photographs of the sea bed were taken at four of the twenty-five stations occupied. At three of these four stations, bottom samples were taken with trawls and grabs.

The detailed examination and description of material collected during the cruise is in progress. In this paper, the unusual bottom fauna shown in the photographs is described in terms of the broader taxonomic groups, specific names being suggested only when there is little doubt of the identification. More precise identification of these animals will be possible when the description of the bottom animals, collected during the cruise, has been completed.

A brief description of the underwater camera used, has been given elsewhere (Hurley, 1959). For the present work, the 35 mm camera was provided with a supplementary lens to correct for chromatic aberration. This lens was similar to that described by Thorndike (1955), but mounted inside the pressure chamber. A pack of $1\frac{1}{2}$ volt dry cells of the most common size replaced the accumulator power supply previously used with the electronic flash.

Results

The positions of the stations at which photographs were taken are shown in Fig. 1. Station data are given in Table 1 and the fauna shown in the photographs is discussed below. The field of view of each photograph is approximately 0·75 metre wide in the foreground, and 1 metre deep.

FIG. 1.—Sketch map showing stations at which bottom photographs were taken.

TABLE 1.

N.Z.O.I. Station No.	Date	Position	Depths (Metres)	Figures
A.468	26/1/59	76° 59′ S, 167° 36′ E	110	2, 3, 4
A.469	29/1/59	77° 50′ S, 166° 33′ E	64	5, 6
A.471	6/2/59	77° 37′ S, 166° 20′ E	69-165	7, 8, 9
A.472	7/1/59	77° 45′ S, 166° 20′ E	391	10

St. A.468, 110 metres (Figs 2, 3, 4)

This station was occupied over the flat top of a steep-sided seamount, which was surrounded by water more than 350 metres deep. Three successive photographs were taken about 100 metres apart, as the ship drifted from east to west across the seamount in a $1\frac{1}{2}$ knot current. The dense fauna is dominated by gorgonaceans, polyzoans, and sponges. These erect branching forms appear to occupy most of the bottom. Conspicuous in Fig. 2, is a large sponge estimated to be 75 cm high

FIG. 2.—Siliceous sponges and coelenterates predominate. Station A.468.

with an osculum 25 cm wide, it may be a *Rosella nuda*. A pycnogonid is attached to the right-hand side of this sponge and a starfish lies at right centre in the picture; patches of a finely branched bushy gorgonacean are also visible. In Fig. 3 a crinoid sits on a sponge (upper left), above it the two arms of a starfish extend into the picture and at top centre, a small fish is resting on the branches of a lamelliform polyzoan. In Fig. 4 a similar fish rests on the sponge lower centre, the crown of tentacles of a sabellid polychaete is visible nearby and whip-like gorgonaceans stand in the background.

FIG. 3.—Dense bottom fauna of filter-feeders. Station A.468.

Visible in these and some of the succeeding photographs, are patches of what look like dusty, irregular cobwebs. The origin and nature of these structures are not known; it is suggested that they are composed of mucous strands.

St. A.469, 64 metres (Figs 5, 6)

These photographs, together with a third, which shows almost the same area, were taken at one lowering of the camera. The ship was moored against the ice, near Hut Point, within 300 metres of the shore. Grab samples yielded many specimens of the dominant mollusc

FIG. 4.—Coelenterates and sponges predominate. Station A.468.

(*Limatula hodgsoni*) and starfish (*Odontaster validus*) shown in the photographs. The sediment was of muddy-sand, containing shell and rock fragments, and heavily matted with sponge spicules. In the grab samples living specimens of *L. hodgsoni* occupied cavities immediately below the surface of the deposit. A live individual with tentacles extended, may be seen in Fig. 5 on the patch of dark deposit below the centre of the picture. A starfish, of the species most common in the photograph, is visible beyond and to the right of this shellfish. In Fig. 6, taken about five minutes earlier, the starfish is closer to the position of the shellfish, but the latter is not visible. Presumably it lies with-

FIG. 5.—Mollusc shells, starfish, sponges, and sea anemones. Station A.469.

drawn in its cavity in the deposit after the close approach of the starfish. Wilson (1951) includes photographs of scallops escaping from starfish by swimming and MacGinitie and MacGinitie (1949) give photographs of sand dollars burrowing out of the way of starfish.

The starfish (*O. valdius*), of which 10 are visible in the photographs, in approximately 1 sq. metre, was also taken in fish traps at this station and is evidently abundant in the area.

The shells of a second species of lamellibranch (*Thracia meridionals*) also collected in the grab samples, are visible a third of the way across

FIG. 6.—Compare Fig. 5 (Stereoscopic viewing of Figs 5 and 6 enhances relief).

the bottom of Fig. 5 from the right-hand side. A trophon gasteropod also taken in the grab samples may be seen directly above the sponge bottom right in Fig. 5 and a pycnogonid stands in the shadow of this sponge. Other sponges are visible in both photographs, as well as two or three sea anemones. A large whitish starfish lies near the centre of each photograph and in the background of each lie lamelliform polyzoa. The intensely white, perhaps luminous object, in the top left of both photographs, has not been identified.

St. A.471, 69-165 metres (Figs 7, 8, 9)

These photographs were taken off Cape Evans, using Ektachrome colour film. Spherical siliceous sponges dominate the scene; even the substrate appears to be composed of living sponges, the oscula of which are evident in Fig. 7. The starfish (*O. validus*) abundant at

FIG. 7.—Sponges, starfish, coelenterates, and the forepart of a fish. Station A.471.

station A.469 is present, possibly associated with the lamellibranch (*L. hodgsoni*) taken in bottom samples at both stations. Other starfish, sabellid tube-worms, a gorgonacean (the finely branched growth in Fig. 7) and the fore-part of a fish are also visible in the photographs. The length of the snout and the shape and position of the fins, suggest the fish is a member of the family Chaenichthyidae.

St. A.472, 391 metres (Fig. 10)

This photograph shows a sparser fauna than that photographed ot the other stations. Six individuals of a sabellid tube-worm, which is perhaps most easily located by the curved shadow cast by its narrow tube, the tubes of other polychaetes, and 6 species of polyzoa are visible. A gorgonacean extends out of the photograph at left centre. A pipe connection, dropped from one of the ships moored against the ice

FIG. 8.—Siliceous sponges. Station A.471.

above, lies right of centre and it has been suggested by Dr H. B. Fell that the animal immediately below and to the right of it is a crinoid. There are abount eight ophiuroids present. The bulbous object left of centre may be a tunicate.

DISCUSSION

Differences between the bottom fauna in Antarctic coastal seas and in the coastal seas of other continents are to be expected when factors peculiar to the Antarctic marine environment are considered. A notable difference is the abundance of siliceous sponges in Antarctic waters. This is illustrated in the accompanying photographs and has been emphasized by Burton (1932) and others.

The absence in Antarctic coastal seas of organic detritus derived from the land and intertidal zone may contribute to the unusual nature

FIG. 9.—Siliceous sponges and tube-worms. Station A.471.

of the bottom fauna, although there may be local exceptions to this in the vicinity of sea-bird and seal colonies. In the absence of terrestrial organic detritus, the bottom environment may be compared with that surrounding small oceanic islands or at comparable depths away from the outfall of continental detritus.

FIG. 10.—Polyzoa, brittle-stars, and tube-worms. Station A.472.

Other significant factors in the environment are, the low water temperature and the summer bloom of phytoplankton.

Four different types of bottom fauna are illustrated by the photographs. The animal group or groups characteristic of each type are as follows.

(1) St. A.468. Gorgonacea, Polyzoa, and Porifera.
(2) St. A.469. Lamellibranchiata and Asteroidea.
(3) St. A.471. Porifera.
(4) St. A.472. Polyzoa, Polychaeta, and Ophiuroidea.

Animals that feed on particulate matter in the water above the bottom, rather than those that ingest sediment, clearly dominate in these faunas. The abundance of filter-feeding forms in the Antarctic was also noted by Pasternak, in his address on the bionomical character of bottom fauna in the Indian Ocean Sector of Antarctica, delivered at a symposium on Antarctic Research held at Wellington, New Zealand, 18-22 February 1958. He considers that they form the main shelf bottom community.

The replacement of the dominant gorgonaceans, polyzoans, and sponges of St. A.468, by sponges as dominants at St. A.471, which in turn have been replaced by bivalves and starfish as dominants at St. A.469, might be related to such variables as the type and supply of food, the water currents, the coverage of pack-ice, the rock debris being deposited from ice floes and bergs and the nature of the bottom sediment.

A westerly directed current past St. A.468 is shown in charts of the area and this prevailed at the time the station was occupied. The existence of this current may explain the abundance of filter-feeding organisms at this station. Where there is only a slight current, sponges may have an advantage over coelenterates and polyzoans, in that the feeding current they generate should enable them to filter a greater volume of water. At St. A.471 sponges are much more abundant than polyzoans and gorgonaceans but, unfortunately, the nature of the currents in this locality is not known.

The relative paucity of the fauna at St. A.472 may be related to the greater depth at this station. A bottom photograph taken at a comparable depth (448 metres) in McMurdo Sound by the United States Navy, during Operation Deep Freeze II, has been published (1957). No precise locality is given. This photograph includes a pycnogonid, a crinoid, some worm tubes, and two patches of sponge. In density of animal life and appearance of sediment it resembles Fig. 10.

It is probable that it was trawls from bottoms such as that at St. A.468 that led T. V. Hodgson, zoologist on the National Antarctic Expedition 1901-1904, to comment on the richness of the fauna, in contrast to the paucity of the flora, in McMurdo Sound (Hodgson, 1907) and to remark, "Everything goes to show that animal life is very abundant in the southern seas." (Hodgson, 1905.)

ACKNOWLEDGEMENTS

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NOTE ON THE IDENTIFICATION OF MANUKA MANNA

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Worley (1928, 1929) reported the occurrence of a colourless, crystalline, water soluble compound which was found in dry weather during mid-summer, on the native species *Leptospermum scoparium*. The occurrence appeared to be associated with the nymph form of *Scolypopa australis* and the larva of the native longhorn beetle, *Aemona hirta*. Other than the preliminary report that manuka manna afforded glucose on hydrolysis and that it was probably a complex sugar no chemical investigation of the substance was undertaken.

Samples of manuka manna collected by Worley, to whom the authors are greatly indebted, have now been examined and identified as D-mannitol which is widespread among plants where it is frequently found in exudates (Lohmar, 1957). In contrast to the report by Worley, repeated hydrolyses of samples of manuka manna gave no evidence for the presence of any sugar when the solutions were examined by paper strip chromatography (aniline hydrogen phthalate spray). The compound was non-reducing and when purified from water as large rods, had m.p. 165° to 166°, undepressed by authentic D-mannitol [Found: C, 39·7; H, 7·9. Calc. for $C_6H_{14}O_6$: C, 39·6; H, 7·75%]. The infrared spectrum was identical with that of an authentic sample and the optical activity was barely perceptible in aqueous solution. The hexa-acetate, prepared by the use of acetic anhydride and fused sodium acetate, crystallized from methanol as needles, m.p. 125° to 126° $[\alpha]_D^{20} + 24{\cdot}6°$ ($CHCl_3$). Lohmar records m.p. 126° and $[\alpha]_D + 25{\cdot}0°$ in $CHCl_3$ [Found: C, 49·8; H, 6·2. Calc. for $C_{18}H_{26}O_{12}$: C, 49·8; H, 6·0%].

Acknowledgement

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STUDIES OF THE ACTION OF MONOBROMAMINE ON *ESCHERICHIA COLI*

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(Received for publication, 24 June 1959)

Summary

The action of monobromamine on bacteria at neutral pH values is rapid, and due to the presence of the monobromammonium ion NH_3Br^+. The monobromamine base NH_2Br has an activity similar to monochloramine. The activity of the monobromammonium ion is comparable with that of free bromine of the same concentration.

Free bromine shows an initial rapid kill of bacteria but under the experimental conditions used, the rate declined due to absorption and destruction of the free bromine.

Introduction

A number of workers (Beckwith and Moser, 1933; Tanner and Pitner, 1939) have made investigations on the action of bromine on bacteria but, owing to their not appreciating the effect of formation of N-bromo compounds, these authors added bromine to suspensions of bacteria in media containing protein and other nitrogenous compounds, and their results gave a confused picture.

Wyss and Stockton (1947) clearly realized this difficulty and worked with nitrogen-free solutions using suspensions of well-washed bacteria. Their work was intended to determine the effects of free bromine, hypo-bromous acid, and hypobromite ion on bacteria, and they performed only a single experiment with bromamine which was made using spores of *Bacillus subtilis* and bromine doses of the order of 20 p.p.m., a quantity very much greater than that used for water sterilization. They found that at pH 7 the bactericidal power of the bromamine was approximately the same as that of free bromine (hypobromous acid).

The present author has made studies of the chemistry of the bromamines in aqueous solution with particular reference to their formation, the existence of mono- and dibromamine and their protonated forms by the use of spectrophotometry and polarography (Johannesson, 1955, 1958a, 1959). At low ammonia nitrogen and bromine ratios dibromamine may be formed (Johannesson, 1958b), and to avoid this possible complication the experiments described in this paper were made in the presence of a sufficient excess of ammonia to eliminate the effect of this substance.

In a recent brief communication the author (Johannesson, 1958c) demonstrated that the bactericidal power of monobromamine was very much greater than that of monochloramine, and that the mechanism of the bactericidal action appears to be different.

N-bromomethylamine and N-bromodimethylamine had a bactericidal activity between monochloramine and monobromamine, the N-bromo-

methylamine being stronger than the dimethyl compound. The logarithm of number of survivors plotted against time showed a very distinct break in the curve for the monobromamine but not for the N-bromomethyl and dimethyl compounds nor for monochloramine.

A systematic investigation was accordingly made of the bactericidal properties of monobromamine, under the conditions that would apply to water treatment, to determine the effect of concentration and pH upon the bactericidal action of monobromamine on *E. coli*.

For the purposes of this paper "free bromine" refers to the mixture of molecular bromine, tribromide ion, hypobromous acid, and hypobromite ion, the proportions of which are a function of pH and Br^- content of the solution. At the pH values used in the experimental work of this paper, hypobromous acid and hypobromite are the only significant entities present. Similarly in the pH range under consideration ammonia may exist as the free base, ammonium ion, and NH_4OH, and it will be referred to simply as "ammonia".

METHODS

Test Organism

The organism used in these studies was a wild strain of *Escherichia coli* type I which was methyl red positive, Voges-Proskauer negative, indole positive, citrate negative, and grew at 44° C. It was maintained on nutrient agar and for the preparation of working suspensions was inoculated into lactose broth for four hours. This culture was used to inoculate tryptose-glucose-meat extract agar plates, which were then incubated overnight at 37° C. The cells were harvested the following morning by centrifuging and washing three times with distilled water. A suspension equal to an approximately 10^9 cells/ml was prepared as the stock working suspension.

Test Solutions

These were prepared by the addition of bromine water to a suitable buffer solution which contained an excess of an ammonium salt when monobromamine was required, and allowed to stand some time in order to meet any oxidizing demand of the solutions. The concentration of active bromine in solution was determined by the ortho-tolidine method using four centimeter cells at 425mμ. Buffers were prepared from 0·01 M phosphates, bicarbonates or borates according to the pH required.

Measurement of Germicidal Action

Quantities of the bacterial suspensions were added to the solutions prepared as above to give a final concentration of 10^6 cells/ml. At suitable time intervals 10 ml aliquots were taken and pipetted into 1 ml quantities of 0·5% sodium thiosulphate solutions and from these solutions counts were made after incubation for forty-eight hours on

MacConkey agar at 37° C. All these experiments were made at a temperature between 55° F and 60° F.

The pH was observed in a Beckman model G pH meter calibrated with potassium hydrogen phthalate at pH 4·0. Absorbance measurements were made with a S.P. 500 Unicam spectrophotometer.

RESULTS

Figures 1 and 2 show results obtained at pH 5·2 and pH 10·8 respectively for both monobromamine and hypobromous acid. The results at intermediate pH values lie between those presented in the above figures.

Frequently, the killing of bacteria is expressed as a monomolecular reaction of the form

$$\text{Log } N_0/N = -kt$$

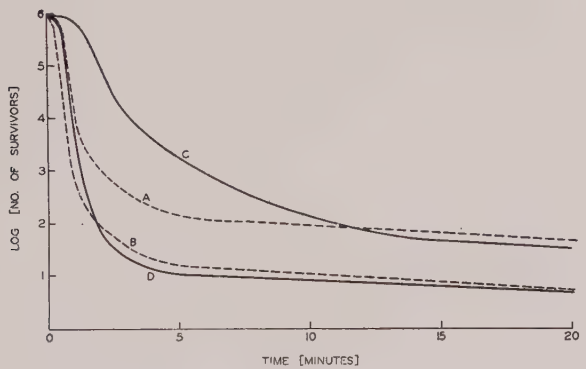

FIG. 1.—Plot of logarithm of the number of survivors against time, pH 5·2.
Broken lines: free bromine A 0·14 B 0·29.
Solid lines: monobromamine C 0·096, D 0·24.

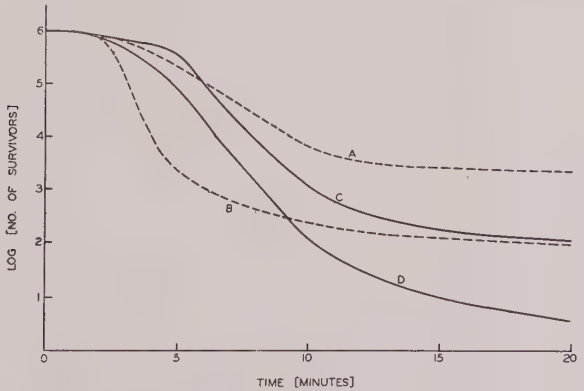

FIG. 2.—Plot of logarithm of the number of survivors against time, pH 10·8.
Broken lines: free bromine A 0·07 p.p.m., B 0·13 p.p.m.
Solid lines: monobromamine C 0·115 p.p.m., D 0·175 p.p.m.

where N_0 = original number of bacteria

N = number of survivors at time t

and it follows from this that a plot of log N against time would give a linear plot (Chick 1908). It is obvious that the results shown in Figs 1 and 2 would not conform to such a law.

These figures reveal that the curves are composed of three portions; an initial induction period which becomes greater with increasing pH or decreasing concentration of the germicidal agent, a period of rapid death, and lastly a period of very slow death of the residual bacteria. This sigmoid type of curve has been found frequently in studies of this type and must be considered more normal than the exponential law.

Frequently, plotting the probit of the percentage survival against the logarithm of time gives a linear plot of results (Finney, 1952; Jordan and Jacobs, 1948), but application of probit analysis to the data presented in this paper gave curvilinear plots and hence offered no advantage over plotting the logarithm of the numbers of survivors against a linear time base.

The author believes that part of the induction period is due to the formation of a diffusion zone around the bacteria similar to that formed around an electrode giving rise to concentration over potentials. In the initial reaction the bacterium survives while absorbing active halogen, thus inducing depletion of the immediate surrounding zone until a diffusion zone is formed. Active molecules then diffuse across the zone until such oxidation or other chemical reaction has effected the death of the organisms.

To make comparisons of the relative rates of killing it was decided to take the inflexion points of the curves and use the time for this value to be reached as the comparison time, as this is the point of maximum mortality.

It has been shown (Chick, 1908) that for many disinfecting agents a plot of the log of time against the log of the concentration of the disinfecting agent will yield a straight line plot, and Fig. 3 shows such a plot made for several experiments at pH 8·2 using monobromamine. It is to be seen that a reasonably straight line graph is obtained. Use of this relationship enabled the inflexion time for the 0·2 p.p.m. concentation to be calculated for each experiment, since exact concentrations of the above strength were difficult to obtain experimentally. The value of 0·2 p.p.m. was chosen, as it fell near the middle of the working range.

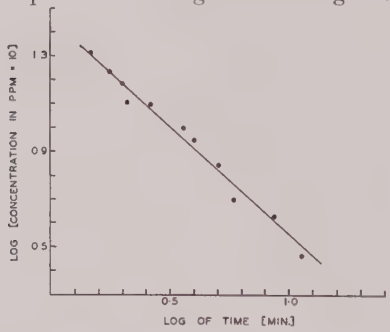

FIG. 3.—Plot of logarithm concentration against logarithm of time for the maximum mortality rates at pb 8·2.

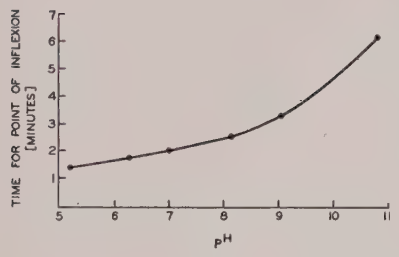

FIG. 4.—Plot of time for point of maximum mortality for 0·2 p.p.m. Br_2 against pH of test solutions.

When the 0·2 p.p.m. values were plotted against pH, the grap shown in Fig. 4 was obtained. The author (Johannesson, 1959) has shown elsewhere that at lower pH values monobromamine forms the monobromammonium ion which has a pKa value of 6·5.

$$NH_2Br + H^+ = NH_3Br^+$$

Examination of Fig. 4 in the light of this suggested that the bactericidal effect was proportional to the concentration of this ion in the test solution, which was confirmed by plotting the logarithm of the time against the logarithm of the proportion of the monobromammonium ion present for each pH. A straight line plot was obtained as shown in Fig. 5. These results indicate that the bactericidal properties of the base monobromamine are of a low order and similar to monochloramine, whereas the activity of the monobromammonium ion is comparable with free bromine and accounts for the strong bactericidal properties of combined bromine at these pH values.

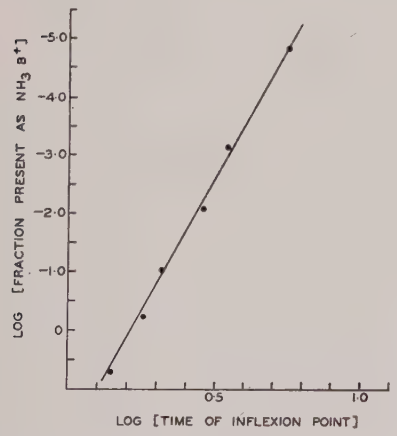

FIG. 5.—Plot of fraction of monobromammonium ion against logarithm of time for point of maximum mortality at 0·2 p.p.m. Br_2.

The pKa for monochloramine is near unity (Weil and Morris, 1949) and in consequence this substance does not show marked changes in bactericidal properties over the pH ranges encountered in water treatment work.

Comparison of the results for hypobromous acid and monobromamine at similar concentrations showed that the initial rate of action of the hypobromous acid was faster but decreased more rapidly. This is in agreement with the residual active halogen found in the solutions, for whereas monobromamine solutions showed but little loss of active strength the loss of hypobromous acid was considerable. Table 1 illustrates this for an experiment made at pH 10·8. This loss of strength explains the rapid decrease of the killing rate for although the free bromine shows an initial killing rate greater than monobromamine it becomes less in time.

The reaction curves suggested that the remaining active bromine compounds were being converted into less active substances which still reacted with the o-tolidine reagent.

$$\text{i.e. } OBr^- + \text{R-}NH_2 \rightarrow \text{R.N.Br}$$

$$H_2NBr + \text{R-}NH_2 \rightarrow \text{R.N.Br}$$

where R could be either an organic grouping or an actual bacterium and eventually complete reduction of the active bromine.

To test this latter hypothesis quantities of the test mixtures at pH 8·2 and containing an excess of free bromine were either filtered through membrane filters or centrifuged in a Foerst continuous centrifuge at 15,000 r.p.m. and the solution and residue examined.

It was found that in the case of the free bromine a yellow deposit of bacterial cells was left in the filters, or in the centrifuge, with very little active halogen remaining in the solution. The yellow mass of bacterial cells smelt strongly of NBr compounds which have a characteristic odour, and reacted with potassium iodide solution to give iodine, and with o-tolidine to form a yellow colour.

In an experiment with monobromamine the cellular residue was free of active bromine and the solution showed no loss of active bromine. This showed that the free bromine had indeed combined with the bacterial cells to form N-Br compounds at the surface of the cell wall. On the other hand there was no action of this type in the bacterial cell with the monobromamine. Examination of the suspension of brominated cells by phase contrast microscopy showed that in both cases the cells were intact and exhibited no evidence of lysis. No information was obtained on the possible formation of active soluble compounds.

Conclusions

It has been demonstrated that, on a bacterium such as *E. coli*, free bromine and monobromamine exhibit a different mode of action.

The rate of killing of bacteria by monobromamine is proportional to the concentration of the monobromammonium ion NH_3Br^+ which is in turn a function of the pH since the monobromammonium ion has a pKa of 6·5. The monobromamine base has bactericidal power similar to that of monochloramine.

It appears that free bromine combines with the bacterial cell to form bacterial-N-Br substance together with liberation of ammonia and complete oxidation of this by the excess of OBr^- in the solution with a corresponding reduction of the excess bromine. Monobromamine does not show this reaction, and it's mode of action is still obscure. Knox, Stumpf, Green, and Auerbach (1948) have suggested that the action of chlorine and chloramine is the inactivation of essential enzymes by attack on essential sulphydryl groups formed. It is likely that bromine

and its compounds behave in a very similar manner. Ingols and others, (1953) have shown a difference in the action of free chlorine and chloramine on sulphydryl groups in that chloramine causes the formation of only disulphide linkages which may be somewhat reversible with cysteine. Free chlorine, on the other hand, causes oxidation not only to disulphide but further to sulphoxides and sulphones, the reactions being irreversible.

The oxidizing power of monobromamine ion is such (Johannesson, 1959) that it would be expected to oxidize beyond the disulphide stage and its action and that of free bromine may be expected to parallel free chlorine in this respect.

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A SURVEY OF POLLUTION IN THE AVON AND HEATHCOTE RIVERS, CHRISTCHURCH, NEW ZEALAND

By. D. J. Hogan and L. Wilkinson, Dominion Laboratory, Christchurch

(Received for publication, 20 August 1959)

Summary

The topography and physical characteristics of the rivers and sources of pollution are described in some detail. Fortnightly samples from points in the tributaries, along the lengths of the rivers, and in their estuary taken at low water over a period of one year were examined chemically and bacteriologically. Average values for the year and four seasons are presented in the form of "profile" graphs which illustrate the changes in river conditions from headwaters to estuary. The discussion elaborates the more signficant results and compares the effect of season, tide, and different river usage on the pollution and hydrography of the two rivers.

Introduction

The enactment of the Water Pollution Act, 1953, was the culmination of many efforts by various individual sections of the community and by central and local administrations to preserve unpolluted waters in their natural state and to prevent or reduce the present pollution of other inland and off-shore waters. The Act established a Pollution Advisory Council "which may carry out surveys and investigations for the purpose of ascertaining the causes, nature, and extent of the pollution of waters".

Christchurch, with an urban population approaching 200,000, is the second largest city in New Zealand. The former excellent facilities for the disposal of the city's liquid wastes are now inadequate, and in consequence the Christchurch Drainage Board has been rapidly expanding its reticulation system during the last few years and has let a contract for a new treatment works. Up to the present time, the great bulk of the city's sewage and domestic wastes, together with some of the trade wastes, is handled at the Drainage Board's farm, and from there the effluents are discharged into the estuary of the Avon and Heathcote rivers. Most of the storm-water drains and many field drains discharge into the rivers upstream from the estuary. The Heathcote River also receives most of the trade wastes. One major outfall drain for storm-water draining a fairly large area of the central city and urban land discharges direct to the estuary at Linwood Avenue. Some of the storm-water drains discharging into the rivers on occasion carry sullage waters and at times of heavy rain sewage can also escape into the two rivers.

In a report to the Christchurch Drainage Board (Scott, 1950) on his investigations into modern methods of sewage treatment and disposal, the Board's Chief Engineer referred to difficulties experienced in

discussing local problems of sewage disposal with overseas experts owing to absence of information on conditions in the Christchurch estuary, and stressed the importance of obtaining basic survey data before conditions might be changed by the proposed new treatment works.

In consequence of the national and local impetus for basic information, the Christchurch branch of the Dominion Laboratory commenced in 1955 a systematic chemical and bacteriological survey of the Avon and Heathcote rivers and their common estuary. Besides providing information on the condition of the various waters, the survey was particularly desirable in that it made possible a quantitative comparison of the effects of different river usage on two rivers which have headwaters in very similar areas and which flow into a common estuary.

PREVIOUS WORK

The first systematic work appears to be a survey of the river channels in the estuary of the two rivers made by the Lyttelton Harbour Board about 1920. Linzey (1944) described the physical features of the estuary of the Avon and Heathcote rivers and gave data on the heights of water, velocities, salinity, pH, and silicate and carbon dioxide concentrations at hourly intervals between one low water and its succeeding low water at the points where the two rivers enter the estuary and additional data on the distribution of saline water, silica, carbon dioxide, and pH at selected points on the two main channels in the estuary at a high- and a low-water period.

In 1951, Bruce (1953) carried out an extensive biological survey of the estuary and also gave chemical and bacteriological data at numerous points in the estuary for a low- and a high-water period during the winter and spring season. On the basis of more extensive salinity measurements, Miss Bruce discussed the probable movement of seawater outside the estuary, and estimated the proportion of river water re-entering the estuary on the flooding tide.

In 1953, Mr H. E. Connor, on behalf of the Christchurch Drainage Board, carried out a botanical survey of the profiles of the two rivers and enumerated the plants found. (Report on Waterweeds in Rivers Administered by the Christchurch Drainage Board—unpublished report in Botany Division, D.S.I.R., Christchurch.)

PHYSICAL CHARACTERISTICS AND SOURCES OF POLLUTION

The topography of the two rivers, their tributaries, and estuary are shown in the map (Fig. 1). In the following descriptive account, the rivers have been divided into three sections for the purpose of comparison of river usage. The three sections are the headwaters, the non-saline section of the main rivers, and the saline tidal sections. The physical characteristics and hydrography of the estuary have been described previously by Bruce (1953) and Wilkinson (1959).

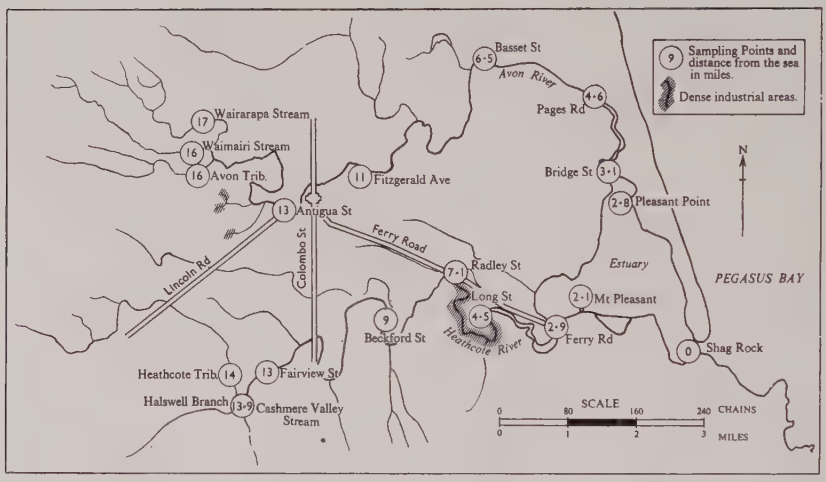

FIG. 1.—Map of the Avon and Heathcote rivers, Christchurch, New Zealand.

Headwaters

Three tributaries comprise the headwaters of the Heathcote River. The most southern and smallest is the Halswell branch or Cashmere Valley Stream, and rises in the hills below the Kiwi Tearooms at the top of Dyers Pass. It flows across grazing fields to meet the Halswell branch a short distance below the bridge in Worsleys Road. It is a slow-moving stream, approximately three yards across at the junction with the Halswell branch, and is frequently covered with weed.

The Halswell branch, or Halswell Creek, has its origin on farmland east of Sutherland's Road, Halswell, and flows in an easterly direction through grazing country to join the Cashmere branch. The combined streams join the Heathcote branch a very short distance downstream. The Halswell branch is substantially larger than the Cashmere branch and is quite fast moving at the confluence.

The Heathcote branch rises as several streams in the southern part of Wigram Aerodrome and flows thence in an easterly direction through farming country until it meets Annex Road at Sunnyside Hospital. It then changes direction to flow south-east through old and new residential areas until it meets the other two tributaries. The Heathcote branch is a clear, rapidly-moving stream, somewhat smaller in cross-section than the Halswell branch, and most of its course is over gravel country.

The Avon also has three major tributaries which converge a little distance upstream from the Carlton Mill bridge. These are all clear and fast flowing.

The southern tributary, the Avon, commences in a large spring just west of Avonhead Road and to the north of Yaldhurst Road, some five

miles from Cathedral Square. For the first two miles it flows in an easterly direction through farming areas and joins shorter streams east of Clyde Road. In the next one and a half miles, the tributary passes through the northern residential area of Riccarton to meet the other two tributaries a little north of the Riccarton railway station.

The middle tributary, known as the Waimairi Stream, has its origin just west of Avonhead Road opposite the Waimairi Road intersection. For the first two miles its course is through farmlands, and the next one and a half miles through the Fendalton residential area, where it is known that septic tank outfalls can seep into the stream.

The northern tributary, known as the Wairarapa Stream, rises east of Wooldridges Road and flows in a south-easterly direction for some one and a half miles through farming areas. For the next two miles it flows through the northern residential area of Fendalton.

Non-saline Zones at Low Water

Below the confluence of its tributaries, the Heathcote meanders through closely-populated residential areas until it reaches the Opawa railway bridge, where there is a change in the character of the river. The distance between the confluence of the tributaries and the Opawa railway bridge is approximately six miles. For the greater part of this stretch there is a gravel bottom, the river is clear and sparkling, and in parts fall is sufficient to provide rapids. About Beckford Street, the bottom changes from gravel to silt and continues to be predominantly silty until Opawa. From the confluence to Opawa bridge there is every appearance of normality in the river. Weed growth is profuse and necessitates weed-cleaning operations by the Christchurch Drainage Board. In this six-mile stretch the following waters enter:

(1) Wilderness drain, which flows from the north alongside the eastern boundary of the Sydenham cemetery across Somerfield Street to meet the river between Young and Studholme streets.

(2) The Bowenvale Valley drain, which joins the river slightly upstream from Bowenvale Avenue.

(3) Jacksons Creek, which rises north-west of the Addington Showgrounds, meanders through Addington and Sydenham, and now enters the Heathcote at Waltham Road.

(4) Two drains, which flow into the river from St. Martin's Valley near Hillsborough Terrace.

(5) Jacksons Creek, which enters the river from the left bank just below Grange Street after passing through Opawa, and was formerly the continuation of drain No. 3.

Between the Opawa railway bridge and the Radley Street bridge, a distance of approximately three-quarters of a mile, there is a marked adverse change in the river, particularly over the last two or three chains just below the entry of a drain which joins the river at Ferry Road. This drain is the Ferry Road-Moorhouse Avenue stormwater

sewer and receives the effluents of the gasworks and several factories in the city area. At Radley bridge, black mud is very evident, the river is often marked by oil and tar slicks on the surface, and on occasion phenolic discharges into the river were observed.

At this point, the flow of the river is markedly affected by the tide, although the salinity of the river at low water shows no significant increase on that upstream. Residential areas border this three-quarters of a mile reach to Radley bridge.

The Avon follows a very meandering course from Riccarton railway station round and through Hagley Park, the central city area, and the north-eastern and eastern residential suburbs of Christchurch.

Two drains, the Riccarton main drain and the Addington drain, carrying trade effluent from the Lower Riccarton industrial area, enter the Avon a short distance upstream from the Christchurch Public Hospital. Two other streams enter the Avon in the stretch between Dallington and Bassett Street. One of these streams, the Dudley Creek, has its origin about Greers Road and near Harewood Road. It passes through the Papanui industrial area and then through several newly-established residential areas where connection to the main city sewerage had not been made at the time of writing. The other stream is the outlet of Horse Shoe Lake, which flows in a southerly direction to join the Avon just downstream from Kerr's Reach. Into the Horse Shoe Lake flow a number of streams which drain the peat lands of Marshlands.

As far as Bassett Street the Avon is a clear, although slowly-flowing river, but from there onwards tidal effects become noticeable and at the Bower bridge muddy sand and absence of vegetation become apparent.

Parts of the Avon River and its tributaries and the Heathcote River are set aside as trout waters for use by younger anglers.

Tidal Zones

The Heathcote River, in the two-and-a-half-mile stretch from Radley bridge to Long Street, passes through an industrial area, and the principal factories discharging effluent into the river include woollen mills, rubber factories, gelatine and glue works, tanneries, engineering works, battery manufactory, fellmongeries, and wool-scouring works. In this stretch the river is noxious and filthy, the bottom is covered by a deep layer of glutinous, black mud which, when disturbed, released hydrogen sulphide. There is no sign of vegetation, and the river is a dumping ground for all kinds of unwanted domestic refuse. At Long Street the water is markedly saline.

Between Long Street and Ferry Road bridge, a distance of approximately two miles, the river passes through farm land principally used for grazing. The bottom gradually changes from the deep, evil-smelling mud, so pronounced in the reach upstream from Long Street, to sand in which crabs and cockles are abundant. While observing changes in

oxygen saturation at Ferry Road bridge, one writer observed that at two hours before low water fish life was moving rapidly downstream.

Just downstream from the Ferry Road bridge, the Heathcote enters the western corner of the triangular estuary.

The Avon between the Bassett Street and Bridge Street bridges has residential areas bordering one bank and farmland bordering the other. The vegetation and animal life change from those characteristics of fresh water to those representative of saline swamp conditions. Numerous field and stormwater drains enter the river in this stretch, but, in contrast with the Heathcote in its tidal reaches, there are no extensive beds of black, offensive mud.

Just below Bridge Street, the Avon enters the estuary at its northern corner.

CHEMICAL AND BACTERIOLOGICAL SURVEY

Sampling and Methods

It is convenient to divide the rivers into the same three sections as in the preceding description. The first comprises the headwater tributaries arising in and flowing through predominantly farming and urban areas. Each of these tributaries was sampled near its confluence with the main stream. The second section comprises the non-saline (low water) portions of the main river flowing through urban areas. In the third section, the rivers are saline and tidal, and it is this section which makes possible the comparison of different river usage. The second and third sections were sampled at the beginning, middle, and end. The estuary was sampled at three points—viz., the Avon channel at Pleasant Point jetty, the Heathcote channel at Mount Pleasant jetty, and the outlet to the sea at Shag Rock.

The positions of the sampling points and their distance in miles from the open sea are shown in Fig. 1. The locations of the sampling points for the headwaters were:

Cashmere Valley Stream	just above confluence with the Halswell branch—sampled from bank
Halswell branch	from Worsleys Road bridge
Heathcote Tributary	from Rose Street bridge
Avon Tributary, Waimairi Stream	from Straven Road bridges
Wairarapa Stream	from Idris Road bridge

At Long Street and Shag Rock, samples were taken about seven feet from the bank. At Pleasant Point and Mount Pleasant, samples were taken from the river channels at the ends of jetties. The other samples were taken midstream from bridges. In all cases, samples were taken just below the surface.

Sampling was carried out at fortnightly intervals during the period February 1955, to March 1956. The samples were taken at low water,

and each river was sampled on twenty-four occasions. Abnormal conditions due to rain, unusual discharge of trade effluent, or weed-cutting were noted on a number of occasions, but rarely extended over the whole or greater part of the rivers. The results of samples taken under abnormal conditions have not been discarded because they lie within the range of results obtained when conditions in the river were normal.

The sampling equipment consisted of a BOD bottle for the dissolved oxygen sample, a 2 lb preserving jar for the chemical sample, and three sterile tubes. These were fastened in a wire basket which was lowered into the river. Dissolved oxygen samples obtained by this method were compared with samples taken under quiescent conditions of filling, but no significant difference in results was found. The dissolved oxygen content of samples stored for 5 hours at atmospheric temperature was not significantly different from that determined immediately on withdrawal from the river. Therefore, no special precautions were taken in storing dissolved oxygen samples other than to commence the test immediately on return to the laboratory.

The temperature of the chemical sample was measured immediately on removal from the river and the samples were later examined for pH (colorimetrically), dissolved oxygen (Winkler, AWWA 1955, p. 252), chloride (Mohr titration), oxygen absorbed from permanganate at 80° F (Taylor, 1949, p. 234), and ammoniacal and albuminoid nitrogens (AWWA 1955, pp. 141, 142).

Total bacterial counts and coliform organisms were determined by a roll-tube technique. Total counts were made on standard nutrient agar at 37° C for 2 days and at 22° C for 3 days. Coliform counts were made on MacConkey agar, total coliforms being determined at 37° C and faecal coliforms at 44° C. The results of the total counts at 37° C and 22° C and of the faecal coliform count at 44° C were the arithmetical means of two of the three bacteriological samples taken at each sampling point. The result of the coliform count at 37° C was the geometrical mean of the three bacteriological samples.

Presentation of Data

The results have been recorded in the following forms:

(1) (a) Arithmetical means (averages) for the year and for the four seasons for chemical measurements.

(b) Geometrical means for the year and for the four seasons for bacteriological counts.

(2) Maximum and minimum values for the year and for the four seasons.

Figure 2 is a block graph comparing all results obtained for the six headwater tributaries.

Figures 3 to 9 are line graphs which illustrate the effect of different river usage on chloride, dissolved oxygen, pH, ammoniacal nitrogen, albuminoid nitrogen, 37° and 44° coliform counts.

Figures 10 to 12 illustrate the seasonal effects on the mean values for chloride, dissolved oxygen, pH, and the two forms of nitrogen.

DISCUSSION

Headwaters

Figure 2 shows that the three Heathcote tributaries had substantially higher mean values for chloride and the two forms of nitrogen than the Avon tributaries and also showed generally a much greater variation in composition. The Heathcote tributary was particularly high in ammoniacal nitrogen. The mean values for pH of the Cashmere Valley Stream and the Halswell Creek were higher than the values for the other four tributaries.

The change in season had a marked and variable effect on the chemical composition of the tributaries. The relative magnitude of the seasonal change was greatest for the two forms of nitrogen and oxygen absorbed. The significance of these changes can be illustrated by the use of Thresh's impurity figure (Taylor, 1949, p. 277):

$$\frac{\text{oxygen absorbed} + 10 \times \text{albuminoid N}}{2}$$

and the ratio ammoniacal N/albuminoid N.

Tables 1 and 2 show the seasonal values for these two expressions for the six tributaries.

TABLE 1.—Effect of Season on "Impurity Figure" in Tributaries at Headwaters of Avon and Heathcote Rivers, 1955–56.

Tributary	Mean "impurity figure" for				
	Year	Spring	Summer	Autumn	Winter
Cashmere Valley	0·9	0·5	0·5	0·4	2·2
Halswell	0·8	0·3	0·5	0·3	1·9
Heathcote	0·6	0·4	0·6	0·4	0·9
Avon	0·4	0·2	0·6	0·2	0·4
Waimairi	0·2	0·2	0·4	0·1	0·3
Wairarapa	0·3	0·2	0·4	0·4	0·3

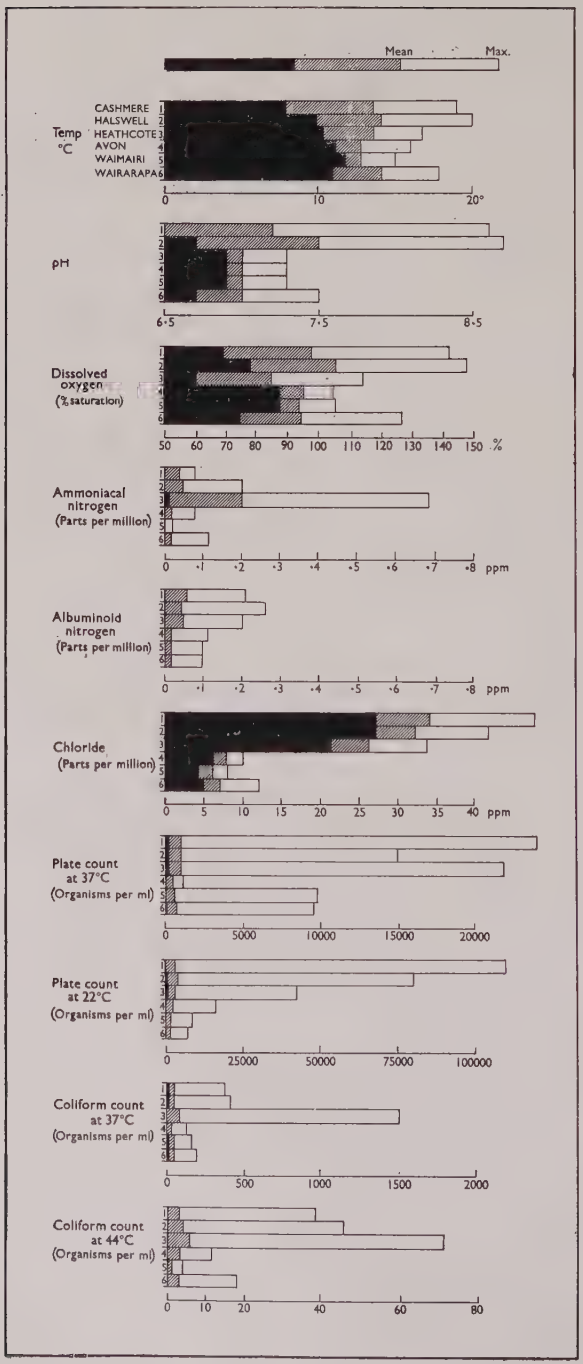

FIG. 2.—Chemical and bacteriological condition of the headwaters of the Heathcote and Avon rivers for the year ended March 1956.

TABLE 2.—Effect of Season on Ammoniacal N/Albuminoid N Ratio in Tributaries at Headwaters of Avon and Heathcote Rivers, 1955–56.

Tributary	Mean value of am.N/alb. N ratio for				
	Year	Spring	Summer	Autumn	Winter
Cashmere Valley	0·6	2·0	1·0	0·5	0·4
Halswell	1·1	4·3	0·9	1·4	0·9
Heathcote	4·8	7·8	1·6	3·6	7·1
Avon	0·6	1·7	0·6	0·8	0·3
Waimairi	0·4	2·0	0·2	2·3	0·3
Wairarapa	0·9	2·0	1·0	0·7	0·6

The seasonal change in pH, dissolved oxygen, and chloride follow roughly the seasonal changes in temperature and are illustrated by the mean values for dissolved oxygen given in Table 3.

TABLE 3.—Effect of Season on Mean Values of Oxygen Saturation in the Tributaries at Headwaters of the Avon and Heathcote Rivers, 1955–56

Tributary	Dissolved oxygen—mean % saturation				
	Year	Spring	Summer	Autumn	Winter
Cashmere Valley	98	103	105	98	85
Halswell	106	103	122	104	85
Heathcote	84	102	70	80	85
Avon	95	99	93	98	91
Waimairi	93	96	92	91	92
Wairarapa	94	112	87	95	81

The scatter of individual results for the bacteriological counts was so great that the small differences found in the seasonal means are not likely to be statistically significant.

The survey showed that the three Heathcote tributaries carried more chloride and nitrogenous matter than the Avon tributaries and were more affected by winter conditions. The Heathcote Stream was particularly high in ammoniacal nitrogen, and, while the ammoniacal N/albuminoid N ratio suggested that this stream is generally subject to contamination by excretal pollution, such a suggestion was not confirmed by any parallel high faecal coliform counts, nor were other occasional high ratios occurring at certain seasons in the other tributaries accompanied by high faecal coliform counts. However, many shallow wells in the Halswell area have a high ammoniacal nitrogen content apparently not associated with excretal pollution. This naturally occurring ammoniacal nitrogen may provide an explanation of the abnormally high ammoniacal N/albuminoid N ratios in the Heathcote Stream.

Supersaturation with oxygen for long periods indicating high algal activity was very marked in the Cashmere Valley Stream and Halswell Creek and to a less extent in the Wairarapa Stream. The relation existing between pH and dissolved oxygen was particularly well marked not only in the headwaters but in all parts of the rivers where there was algal activity.

Non-saline Water Sections

Figures 3 to 9 show that the freshwater section of the Heathcote River had a naturally higher mean chloride content, was less subject to faecal pollution, and was, in general, less variable in composition than was the corresponding section of the Avon. The survey showed that substantial recovery from pollution had been effected in the Avon by the time it had reached the downstream limit of the freshwater section about Bassett Street, whereas no such recovery was evident at the corresponding position in the Heathcote at Radley Street owing to the combined effects of pollution from the drain immediately upstream and of the heavy pollution of the downstream tidal waters.

The more significant effects of season on the two rivers are illustrated in Figs 10 to 12. Supersaturation with oxygen, accompanied by high pH, during the spring, summer, and autumn seasons occurred more frequently and to a greater extent in the Heathcote than in the Avon, and the changes between fortnightly samples were generally less abrupt in the former river. Although, as noted in the previous paragraph, the survey showed that the Heathcote at Radley Street was polluted, the river at this point was saturated with oxygen from late winter until the middle of summer, and this supersaturation is taken to indicate that the pollution noted above was entering only a very short distance upstream and presumably from the drain described previously. During the late autumn and winter periods, both rivers were somewhat deficient in oxygen, the deficiency being generally greater in the Heathcote.

The values of the various pollution indices for both rivers were usually greatest during the winter period, but, in general, fluctuations in values in both rivers were less pronounced during the winter than at other times of the year.

During summer, high values for various pollution indices were noted at Antigua Street, and suggest that the most significant pollution entering the river is that from one or both drains originating in Riccarton. In winter, high values for the two forms of nitrogen, their ratio, and 44° C coliform counts were noted at the Fitzgerald Avenue sampling point and suggest that considerable pollution of faecal origin is entering the Avon upstream from this point. Overflows from the city sewerage could occur just upstream from this bridge.

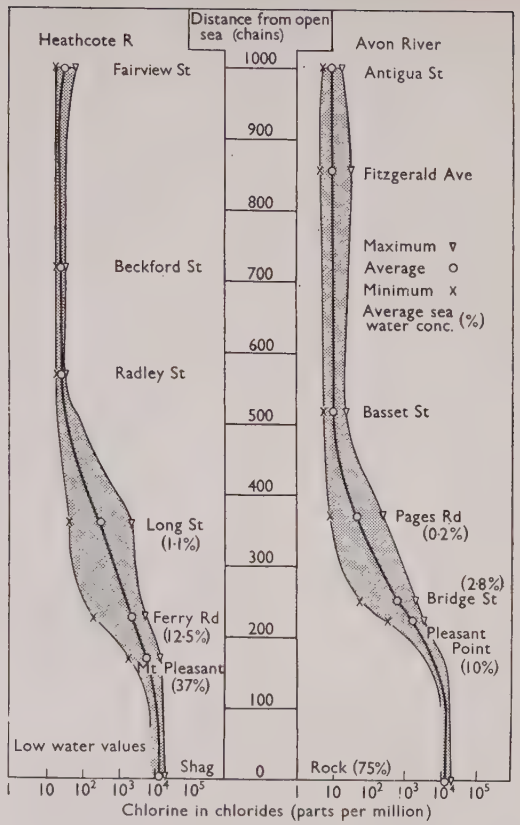

FIG. 3.—Chlorides V profile. Average and range for year ended March 1956.

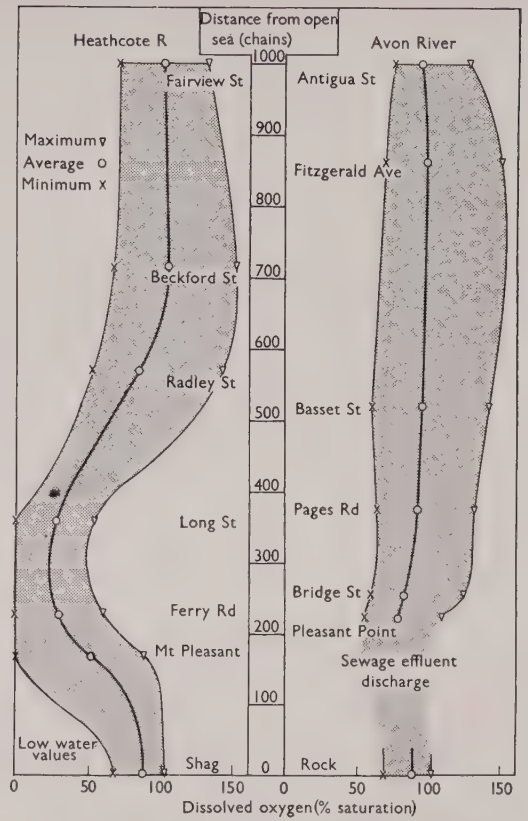

FIG. 4.—Dissolved oxygen V profile. Average and range for year ended March 1956.

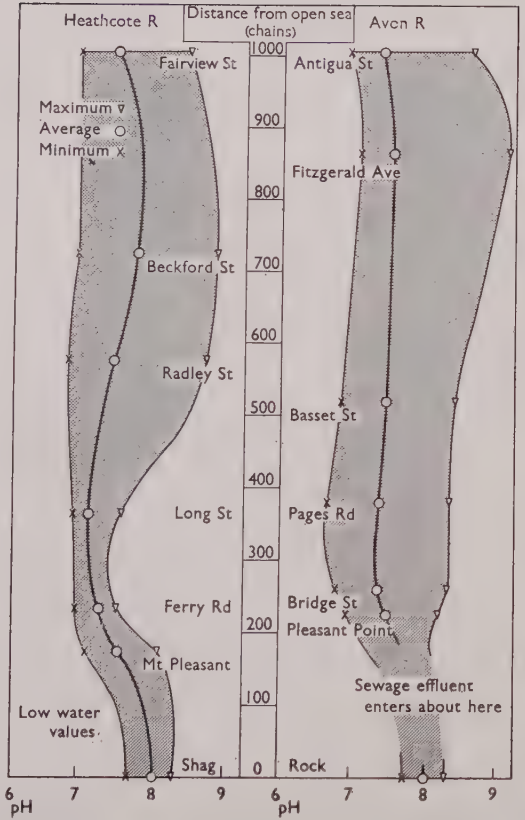

FIG. 5.—pH V profile. Average and range for year ended March 1956.

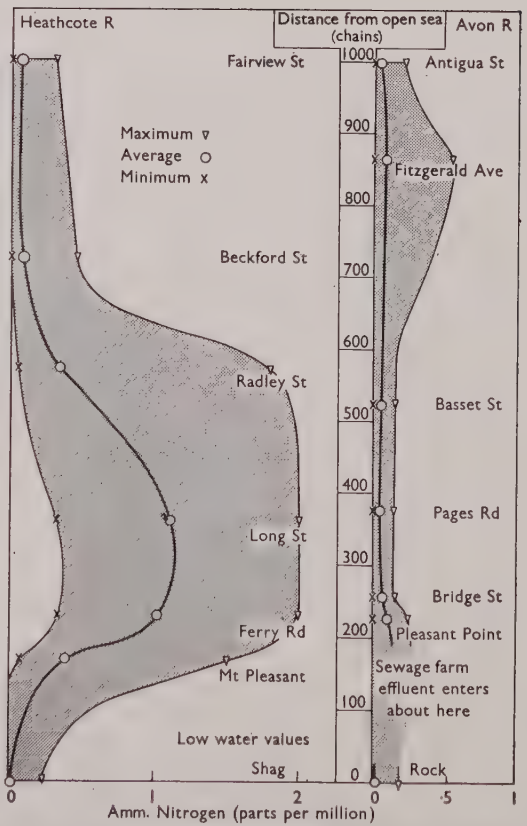

FIG. 6.—Ammoniacal nitrogen V profile. Average and range for year ended March 1956.

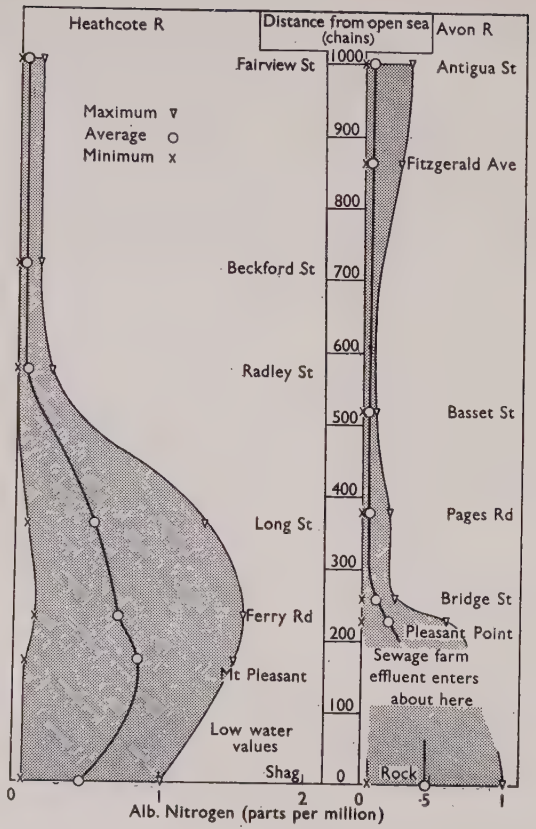

FIG. 7.—Albuminoid nitrogen V profile. Average and range for year ended March 1956.

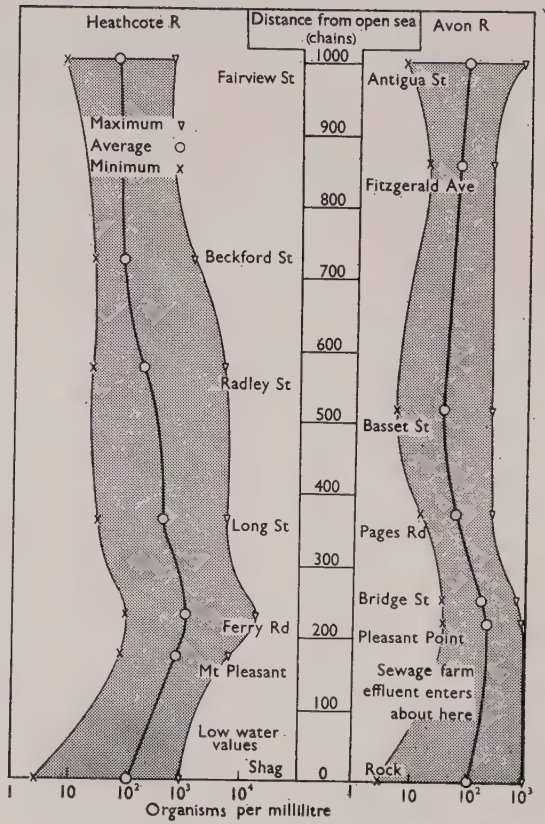

FIG. 8.—37° C coliforms V profile. Average and range for year ended March 1956.

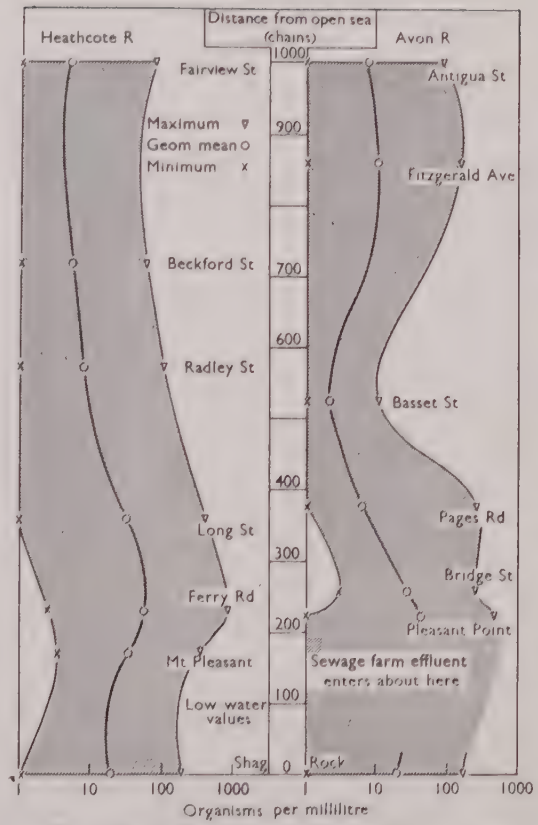

FIG. 9. 44° C coliforms V profile. Average and range for year ended March 1956

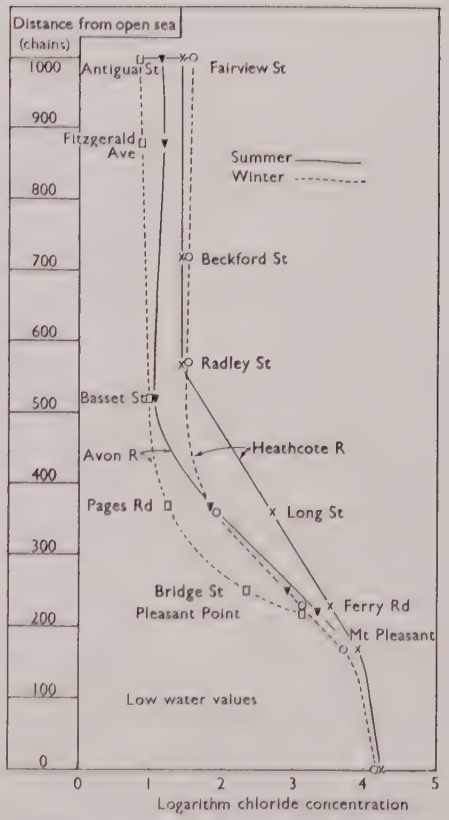

FIG. 10. Summer and winter variations in chloride V profile.

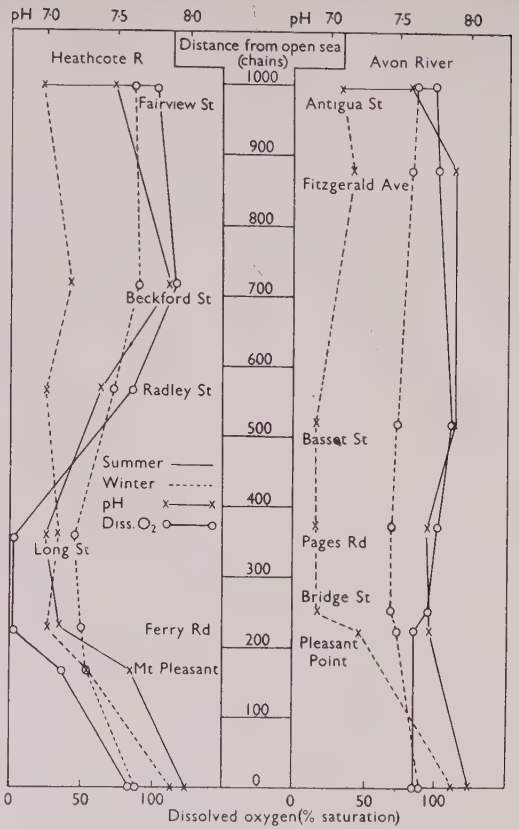

FIG. 11.—Summer and winter variations in pH and dissolved oxygen V profile.

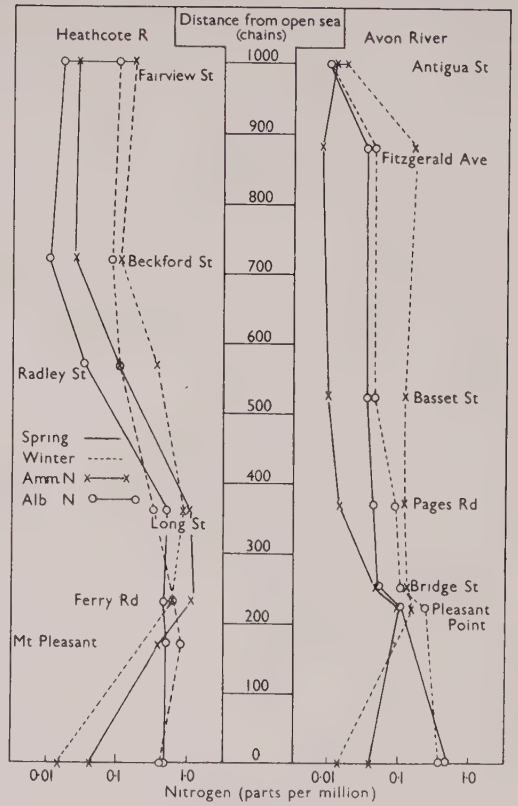

FIG. 12.—Summer and winter variations in ammoniacal and albuminoid nitrogens V profile.

Tidal Sections

Figures 3 to 9 give a quantitative evaluation of the relative degree of pollution in the tidal zones of the two rivers and illustrate the effect of discharging industrial pollution into a small river or stream. Whereas the tidal zone of the Avon showed on the whole little deficiency in oxygen and was often supersaturated in spring and summer, the Heathcote had an average saturation of less than 30%, and during the summer was on many occasions completely devoid of dissolved oxygen. The mean yearly values of ammoniacal and albuminoid nitrogen in the Heathcote were about 20 and 10 times the values found for the Avon, and differences of the same order exist between the two means for oxygen absorbed, "impurity figure", and various bacterial counts. Compared with the Avon, individual sampling stations in the tidal reaches of the Heathcote showed very marked variations in the two forms of nitrogen and oxygen absorbed.

Some information on the effect of tide on dissolved oxygen in the polluted Heathcote was obtained by measurements made on 12 March 1956 at Long Street and Ferry Road. The day was bright and sunny, with a light south-westerly wind in the early morning changing to easterly at 11 o'clock. Results are given in Tables 4 and 5.

TABLE 4.—Variation in Composition of Samples Taken from Ferry Road Bridge on 12 March 1956.

Time	Flow of water	Chloride (p.p.m.)	Dissolved oxygen (% satn.)
7.05 a.m.	Ebbing	16,000	71
7.30 a.m.	Ebbing	16,000	68
8.30 a.m.	Ebbing	13,000	47
9.30 a.m.*	Ebbing	10,000	32
10.00 a.m.	Ebbing	8,000	23
10.30 a.m.	Ebbing	6,400	20
11.00 a.m.	Ebbing	4,600	11
11.30 a.m.	Dead low	3,600	14
12.00 noon	Flooding	4,000	14
12.30 p.m.	Flooding	5,800	17
1.30 p.m.	Flooding	10,000	68
2.00 p.m.	Flooding	14,500	78
2.30 p.m.	Flooding	15,000	83
3.00 p.m.	Flooding	15,000	85
3.30 p.m.	Flooding	16,300	92
4.00 p.m.	Flooding	16,500	—
4.30 p.m.	Flooding	17,500	97
5.00 p.m.	Flooding	17,500	97
5.30 p.m.	Dead high	18,000	100
6.00 p.m.	Ebbing	18,500	100
6.30 p.m.	Ebbing	17,500	93
7.00 p.m.	Ebbing	17,500	91
7.30 p.m.	Ebbing	17,500	93

*Sprats observed swimming downstream.

TABLE 5.—Variation in Composition of Samples Taken off Bank at Long Street on 12 March 1956.

Time	Flow of water	Chloride (p.p.m.)	Dissolved oxygen (% satn.)
7.00 a.m.	Ebbing	6,400	7·8
9.00 a.m.	Ebbing	2,900	1·1
11.00 a.m.	Ebbing	700	0·8
12.00 noon	Dead low	700	Nil
2.00 p.m.	Flooding	1,300	3·4
3.00 p.m.	Flooding	2,000	12·4
4.00 p.m.	Flooding	3,800	23
5.00 p.m.	Flooding	6,100	35
6.00 p.m.	Ebbing	5,400	32
7.45 p.m.	Ebbing	5,500	25

At Ferry Road (Table 4), the morning tide raised the dissolved oxygen content and at high water the river was fully saturated with oxygen. A serious deficiency in oxygen existed, however, during the three and a half hour period about low water.

Table 5 shows that, even at high water, the river at Long Street contained barely enough oxygen to support fish life, and for the whole of the morning it was, for practical purposes, completely devoid of oxygen.

Estuary Channels

The Heathcote channel at Mount Pleasant jetty had higher mean values for the year for the two forms of nitrogen, oxygen absorbed, impurity figure and most of the bacterial counts, and lower mean oxygen saturation than the Avon channel at Pleasant Point, indicating that upstream pollution was still exerting a marked effect on the condition of the Heathcote channel waters.

The mean values of the various pollution indices of the Avon at Pleasant Point compared with those at the upstream sampling points indicate that it was more polluted in the estuary than upstream, and as there are no sources of entering pollution between Pleasant Point and Bridge Street, this suggests that the higher pollution found at the former originates in the estuary.

Two sewage effluents from the Christchurch Drainage Board's treatment farm enter the Avon channel downstream from the jetty. Miss Bruce concluded that sewage material was being carried upstream to Bridge Street by an incoming tide. The data obtained in 1953 (Wilkinson, 1959) shows that there is no certainty that sewage material was

carried upstream as far as Pages Road bridge. The main sewage effluent from the Christchurch Drainage Board's farm enters the Avon channel only 30 chains downstream from the Pleasant Point jetty, and it might be expected that low-water samples at the sampling station could therefore on occasion reveal sewage matter which had passed upstream on the previous tide. High 44° C coliform counts and ammoniacal N:albuminoid N ratios greater than 2 were noted on 6 and 3 occasions resectively, and the detailed results for these samples are given in Table 6.

TABLE 6—Detailed Analysis of Individual Low-water Samples Taken at Pleasant Point Jetty, Showing High 44° C Coliform Counts or High Ammoniacal/Albuminoid Nitrogen Ratios.

Date of sample	44° C Coli count (ml)	Ratio amm. N/ alb. N	Amm. N (p.p.m.)	Alb. N (p.p.m.)	Diss. O_2 (%satn.)	O_2 abs (p.p.m.)
4/4/55	440	0·1	0·038	0·35	58	1·3
7/6/55	110	1·9	0·24	0·15	70	3·4
3/10/55	92	1·6	0·14	0·09	91	1·7
14/11/55	0·5	4·0	0·14	0·035	97	1·8
28/11/55	130	0·7	0·14	0·20	89	1·4
12/12/55	29	13	0·08	0·006	110	1·3
9/1/56	110	0·6	0·14	0·22	75	1·3
20/2/56	210	2·0	0·24	0·12	81	1·0
5/3/56	35	2·3	0·18	0·077	71	0·5

Table 6 shows that the high 44° C coliform counts were not generally associated with high ammoniacal N:albuminoid N ratios as might be expected if the pollution was principally due to relatively fresh sewage effluent. On the three occasions when high nitrogen ratios were found, the counts for 44° C coliforms were low. Thus there is no clear-cut evidence that the Avon channel at Pleasant Point jetty was polluted at low water by sewage effluent. The most surprising feature of Table 6 is that 44° C coliform counts showed a better correlation with albuminoid nitrogen than with ammoniacal nitrogen.

The effect of the various sewage effluents on the composition of the water at Shag Rock cannot be assessed directly from the absolute values found there due to the increase in salinity.

In order to eliminate the variations in dilution by seawater, certain of the mean values for the year have been recalculated (Table 7) on a freshwater basis assuming that the seawater was saturated with oxygen and had substantially nil values for the other measurements.

TABLE 7.—Mean Values for the Year Calculated on a "Fresh Water" Basis at Three Sampling Points in the Estuary.

Measurement	Pleasant Point	Mount Pleasant	Shag Rock (a)	Shag Rock (b)
Oxygen saturation %	78	28	45	71
Oxygen absorbed (p.p.m.)	1·9	4·2	3·5	2·4
Ammoniacal N (p.p.m.)	0·11	0·57	0·085	0·17
Albuminoid N (p.p.m.)	0·19	1·30	2·3	0·35
Plate count/ml 37°C	1,800	8,000	5,500	2,700
Plate count/ml 22°C	6,000	33,000	14,000	10,000
Coliform count/ml 37° C	250	1,000	550	360
Coliform count/ml 44°C	45	52	85	46

(a) Calculated from observed value at Shag Rock.

(b) Calculated from values and relative volumes of water in channels at PleasantPoint and Mount Pleasant.

The body of water of non-saline origin passing Shag Rock will be a mixture of aged estuarine water and fresh river waters together with the various sewage effluents discharged into the estuary.

It is evident from the oxygen saturation values shown in Table 7 that, separately or together, sewage effluents and decomposing plant material are exerting considerable effect on the composition of the water at Shag Rock. The roughly comparable bacteriological results in the "a" and "(b)" columns for Shag Rock indicate, however, an enormous reduction in the millions of bacteria introduced by sewage effluents, which comprise one-tenth to one-twentieth of the volume of non-saline water entering the estuary.

Table 7 shows also a significant loss in ammoniacal nitrogen by the time the estuarine waters reach Shag Rock. On the other hand, the albuminoid nitrogen found at this place is very much higher than expected. It is almost certainly the result of decomposition of ulva. Miss Bruce has described the extensive beds of this plant which occur in many parts of the estuary. It is known that on occasion floating ulva oscillates with the tide in large quantities.

The spring dissolved oxygen value at the three sampling points were higher than those for the other seasons in contrast with the rivers where summer values were highest. There was some evidence of greater pollution accompanying the increased run-off during winter at Pleasant Point and Mount Pleasant.

Changes in the Rivers Over Long Periods

The only published data on the composition of the estuary waters are those of Linzey (1944) and Bruce (1953). A comparison of this previous work with the present survey shows agreement in most cases. The few discrepancies which occur are illustrated by the results at two sampling points given in Table 8.

The table shows that the chloride values of Linzey and Miss Bruce are much lower than those recorded for the corresponding periods in 1955. The lowest value recorded at Pleasant Point by the writers in 1955 was 460 p.p.m. chloride on 9 May, two days after full moon in fine weather. Another low value at Pleasant Point of 790 p.p.m. chloride was recorded on 12 December 1955, two days after the first quarter of the moon.

The lowest value found in 1955 at Ferry Road was 200 p.p.m. chloride on 30 August, one day after the last quarter of the moon and on a bright sunny day with an easterly wind. Only one other value of chloride less than 1,000 p.p.m. was recorded at Ferry Road, and that was a value of 420 p.p.m. on 25 July 1955, two days after full moon.

TABLE 8.—Comparison of Previously Published Results with 1955–56 Survey Pleasant Point Jetty and Ferry Road Bridge.

Sampling points and determination	Linzey Oct.-Nov. 1941	Bruce Sept. 1951	Survey Sept.-Nov. 1955	Bruce June 1951	Survey June-Aug. 1955
	Results of low-water samples				
PLEASANT POINT					
pH	7·2	7.2	7·1–8·1	6·7	6·9–7·5
Chloride	300	465	920–4,000	128	1,100–1,800
D.O.	—	9·4	5·3–9·5	6·7	6·8–9·2
O_2 abs.	—	1·3	1·4–2·4	2·3	1·8–3·5
Amm. N	—	0·10	0·013–0·19	0·29	0·083–0·24
Alb. N	—	0·12	0·035–0·20	0·13	0·1–0·6
N.A. 37° C	—	5,000	1,000–3,600	500	200–8,500
N.A. 22° C	—	55,000	3,900–16,000	96,000	1,200–20,000
Coliform 37 C°	—	>100	36–630	70	91–890
FERRY ROAD					
pH	7·6	7·3	7·2–7·5	7·0	6·9–7·1
Chloride	600	142	1,300–3,700	120	200–2,500
D.O.	—	7·8	0·2–5·9	6·7	3·2–6·9
O_2 abs.	—	3·4	2·3–4·4	7·5	3·2–5·6
Amm. N	—	0·55	0·7–1·8	—	0·35–0·9
Alb. N	—	0·51	0·22–1·8	—	0·32–1·0
N.A. 37° C	—	10,000	2,700–16,000	30,300	1,000–8,000
N.A. 22° C	—	500,000	5,500–140,000	220,000	9,800–38,000
Coliform 37° C	—	>100	310–6,200	70	120–1,700

Chemical values are expressed in parts per million and bacteriological results as counts per ml.

It is evident that Linzey's and Miss Bruce's samples were taken when hydraulic conditions in the rivers were very different from those obtaining in 1955–56.

Variation in Salinity of the Rivers

Figure 10 shows the mean chloride values for the summer and winter periods in the two rivers. In the non-saline stretches of the Heathcote, the greater winter run-off may account for a slightly higher chloride content in winter compared with summer. This was noticed also in the tributaries of the Heathcote. Increased run-off during winter makes little difference to the chloride content of the Avon freshwater stretches or its tributaries. The higher summer values in the Avon result from additional pollution received upstream from Antigua Street footbridge, since they do not occure in the Avon tributaries.

In the tidal reaches of the two rivers, the increased run-off during winter reduces the average salinity very considerably, as shown in Table 9.

Table 9 also shows that, particularly in winter, hydraulic conditions at Ferry Road are much closer to those at Pleasant Point than those at Bridge Street. Although Long Street and Pages Road are roughly the same distance from Shag Rock, conditions at the former are generally intermediate between the latter station and the next station well downstream—viz., Bridge Street.

TABLE 9.—Effect of Season on Salinity at Sampling Stations on Tidal Reaches of the River and Their Channels in the Estuary.

Sampling point	Distance from sea (chains)	Mean value of seawater content				
		Year	Spring	Summer	Autumn	Winter
Shag Rock	0	80	85	80	80	75
Mount Pleasant	170	36	43	42	35	27
Ferry Road	230	12·5	12·5	16	15·5	7
Pleasant Point	220	10	11	11	12	7
Bridge Street	250	2·8	2·6	4·1	3·3	1·1
Long Street	360	1·8	1·4	2·5	3·0	0·4
Pages Road	370	0·3	0·3	0·35	0·3	0·1

CONCLUSIONS

(1) As determined by analysis, the condition of the six tributaries was substantially the same. The dissolved oxygen content was uniformly high and the streams were generally supersaturated in spring and summer. The Heathcote River, however, had a comparatively high ammoniacal nitrogen content which did not appear to be associated with faecal pollution, but could have been associated with shallow well waters known to be high in ammoniacal nitrogen.

(2) In the freshwater sections of the main rivers, the Heathcote was less subject to faecal pollution by drains and sewage overflows and was more supersaturated with oxygen than the Avon River. The latter, however, recovered before the saline tidal section, whereas additional pollution entering the Heatcote River prevented an assessment of recovery. The Avon River was appreciably polluted at Antigua Street and Fitzgerald Avenue.

(3) The survey graphically illustrates the comparative effects of normal urban and industrial areas which border the saline tidal sections. At no time did a serious deficiency in dissolved oxygen exist in the Avon River, whereas in the Heathcote River during summer the average concentration at low water was less than 30%, and in March at Long Street serious deficiencies were found at all stages of a tidal cycle. As measured by the nitrogen contents, the Heathcote was ten to twenty times more polluted than the Avon.

(4) The effect of the upstream pollution was still marked in the Heathcote channel at Mount Pleasant jetty. There was more pollution, however, in the Avon channel at Pleasant Point jetty than upstream, and some pollution therefore had originated in the estuary. Inconsistency between the various pollution indices invalidates their use for a direct assessment of the extent of the oscillation of sewage effluent discharged into the Avon channel. The sewage bacteria were enormously reduced in numbers by the time the waters had reached Shag Rock.

This reduction in numbers of bacteria was accompanied by a decrease in ammoniacal nitrogen. Owing to the beds of ulva in the estuary and other sources, there was an increase in albuminoid nitrogen at Shag Rock. The movement of water in and sources of pollution within the estuary should be studied in much greater detail.

(5) The seasons had a marked but variable effect on the two rivers. The tributaries and freshwater sections of both rivers were more polluted during winter than at other seasons. In the saline tidal sections, however, the difference in river usage was most clearly marked during

summer, when biological activity is at a maximum. In the heavily-polluted Heathcote saline sections, the increased biological activity led to such rapid decomposition of polluting material that the demand for oxygen exceeded the supply, even though the upstream waters were supersaturated with oxygen. In the Avon, however, the abundant supply of oxygen provided by the stimulated algal and weed growth upstream was more than sufficient to provide for demands of decomposing matter in the saline sections, and dissolved oxygen levels in summer were therefore generally well above those at other seasons.

(6) Very few comparisons with previous work are possible, but such data as are available suggest that there may be marked changes in the hydraulic conditions in the estuary since 1941.

(7) The faecal coliform count correlated better with albuminoid nitrogen than with ammoniacal nitrogen, and this warrants further study.

(8) The survey shows clearly that the Heathcote River cannot cope with the polluting matters which at present are discharged into or which exist in the river. The Avon River, on the other hand, is able to deal satisfactorily with the present pollution. The estuary therefore at the present time is virtually an oxidation pond for the treatment of polluted matters from the Heathcote River and various sewage effluents. Such conditions will naturally encourage growth of ulva, and the subsequent decay of this contributes further to the oxygen demand in the estuary. Conditions in the lower reaches of the Avon are undoubtedly influenced by the oscillation of polluted estuarine waters. Although the new sewage treatment works will alleviate to some extent conditions in the estuary, the recreational use of these waters is of sufficient importance to warrant the more detailed examination of estuarine conditions as suggested in conclusion (4).

ACKNOWLEDGEMENTS

The authors are indebted to Mesdames S. Teague and D. Palmer and to Miss C. A. Loach for assistance with analyses; to Mr E. F. Scott, Chief Engineer of the Christchurch Drainage Board, for criticism of the manuscript; and to Mr N. P. Alcorn, Government Analyst, for encouragement and helpful advice.

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CONTRIBUTIONS TO A CHROMOSOME ATLAS OF THE NEW ZEALAND FLORA—3

MISCELLANEOUS FAMILIES

By E. J. Beuzenberg and J. B. Hair, Botany Division, Department of Scientific and Industrial Research, Christchurch

(Received for publication, 23 April 1959)

Summary

Documented chromosome numbers are provided for 9 species of the Lobeliaceae, 13 species and 3 varieties of the Violaceae, and for 3 species and 1 reputed hybrid in *Fuchsia* (Onagraceae).

Acknowledgements

Miss L. B. Moore, Senior Botanist, Botany Division, D.S.I.R., kindly identified material of the Violaceae and checked the nomenclature used in this study. For living material supplied, the authors are indebted to their colleagues and particularly to Mr W. B. Brockie, Otari Gardens, Wellington; Mrs V. M. Scott, of Takaka, Nelson; Professor G. T. S. Baylis and Mr B. W. Campbell, of Dunedin; and Mr V. C. Davies and Mr R. Hair, of New Plymouth.

TABLE 1.—*Documented Chromosome Numbers* of New Zealand Plants: Miscellaneous Families.

Species	n	2n	Source	Herb. No.
LOBELIACEAE				
Colensoa physaloides (A. Cunn.) Hook. f.	13	26	Cultivated plant, New Plymouth	100863
Isotoma fluviatilis (R. Br.) F. Muell. ex Benth.	7	14	Vicinity Mt. Potts, Canterbury	100035
			Lake Wairarapa ,Wellington Province	100173
Lobelia anceps Linn. f.	7	14	Aorere River, near Bainham, Nelson*	101236
L. linnaeoides (Hook. f.) Petrie	7	—	Kakanui Mountains, Otago*	101238
L. roughii Hook. f.	—	14	St. Arnaud Range, Nelson	101961
Pratia macrodon Hook. f.	7	14	Mt. Murphy, Marlborough	100430
			Timm's Creek, Canterbury	101036
P. perpusilla Hook. f.	21	—	Lake Ohau, South Canterbury*	100989
P. angulata (Forst. f.) Hook. f.	35	—	Blackwater Creek, Hohonu S.D., Westland	100041
P. arenaria Hook. f.	35	—	Chatham Islands*	101237

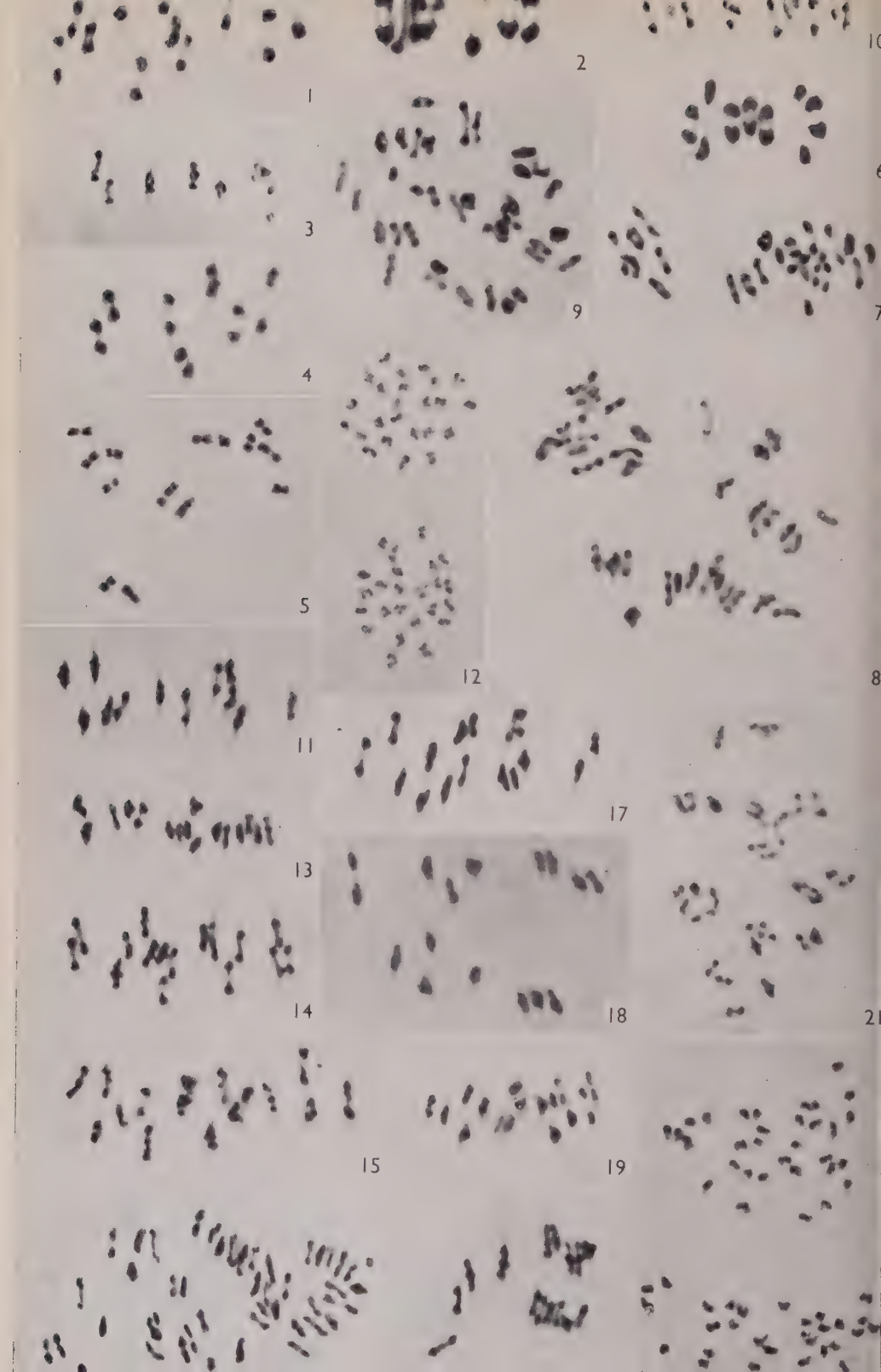
ONAGRACEAE				
Fuchsia excorticata (Forst.) Linn. f.	11	—	Botanic Gardens, Christchurch	200293
F. colensoi Hook. f.†	11	—	Riccarton Bush, Christchurch	200300
F. perscandens Ckn. et Allan	11	—	Riccarton Bush, Christchurch	200301
F. procumbens R. Cunn. ex A. Cunn.	11	22	Cultivated plants, Auckland	200302–3
VIOLACEAE				
Viola lyalli Hook. f.	12	24	Blackwater Creek, Hohonu S.D., Westland	100069
			Lake Wairarapa, Wellington Province	101271
V. cunninghamii Hook. f.	24	48	Vicinity Bealey, Canterbury	100017
			Mt. Herbert, Banks Peninsula	100291
			Molesworth, Marlborough	100410
			Fog Peak, Mt. Torlesse, Canterbury	100652
			Porter's Pass, Canterbury	100976
			Balmoral, North Canterbury	101278
V. filicaulis Hook. f.	36	—	Lower Pouakai Range, Tataraimaka, Taranaki	100598
			Tongariro, National Park	100782
			Mt. Cargill, Dunedin	101132

TABLE 1.—*Continued.*

Species	n	2n	Source	Herb. No.
Melicytus ramiflorus Forst.	16	32	Tataraimaka, Taranaki	100552
			Peel Forest, South Canterbury	100669
			Riccarton Bush, Christchurch	200163
M. macrophyllus A. Cunn.	16	32	Cultivated plant, New Plymouth	100846
			Bay of Islands*	200167
M. lanceolatus Hook. f.	16	32	Botanic Gardens, Christchurch	200168
			Dawson's Falls, Mt. Egmont*	200169
			Cultivated plant, New Plymouth	200171
var. ***latior*** Simpson et Thomson	—	32	Flagstaff Hill, Dunedin	200170
M. micranthus Hook. f.	48	96	Price's Valley, Banks Peninsula	101629
			Price's Valley, Banks Peninsula	200194
			Riccarton Bush, Christchurch	101631
			Riccarton Bush, Christchurch	200195–7
var. ***longiusculus*** Cheesem.	—	64	Price's Valley, Banks Peninsula	101630
var. ***microphyllus*** (Col.) Cheesem.	—	96	Price's Valley, Banks Peninsula	101632
			Botanic Gardens, Christchurch	200201

Hymenanthera chathamica (F. Muell.) Kirk	16	32	Cultivated plant, New Plymouth	100847
			Cultivated plant, New Plymouth	100850
			Cultivated plant, New Plymouth	101306
			Botanic Gardens, Christchurch	200175
H. novae-zelandiae (A. Cunn.) Hemsl.	16	32	Cultivated plant, New Plymouth	100849
			Botanic Gardens, Christchurch	200179
H. obovata Kirk	16	32	Takaka, Nelson	96346–7
			Cultivated plant, New Plymouth	100851
			Botanic Gardens, Christchurch	200180
H. angustifolia R. Br. ex. D.C.	16	32	Springs Junction, Nelson	101748
			Springs Junction, Nelson*	200183
	32	—	Botanic Gardens, Christchurch	200184–5
H. alpina (Kirk) W. R. B. Oliver	32	64	Botanic Gardens, Christchurch	200186–9
			Mt. Peel, N.W. Nelson*	200190
			Lower Clarence River, Marlborough*	200191
			Mt. Herbert, Banks Peninsula	100869
H. classifolia Hook. f.	32	64	Botanic Gardens, Christchurch	200192–3
			Mt. Evans, Banks Peninsula	100870

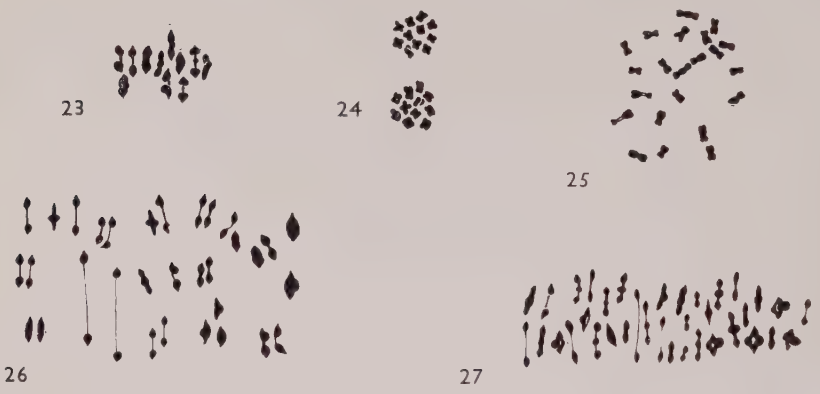
†Reputed hybrid between *F. excorticata* and *F. perscandens.*
*Grown on at Otari Gardens, Wellington.



Unless otherwise stated, all figures are of first metaphase of meiosis. × 1500.

Fig. 1.—*Colensoa physaloides* (n = 13), 13^{II}.
Fig. 2.—*Isotoma fluviatilis* (n = 7), 7^{II}.
Fig. 3.—*Lobelia anceps* (n = 7), 7^{II}.
Fig. 4.—*L. linnaeoides* (n = 7), 7^{II}.
Fig. 5.—*L. roughii* (2n = 14), mitotoic metaphase.
Fig. 6.—*Pratia macrodon* (n = 7), 7^{II}.
Fig. 7.—*P. perpusilla* (n = 21), 21^{II}.
Fig. 8.—*P. angulata* (n = 35), 35^{II}.
Fig. 9.—*P. arenaria* (n = 35), 35^{II}.
Fig. 10.—*Fuchsia colensoi* (n = 11), 11^{II}.
Fig. 11.—*Viola lyalli* (n = 12), 12^{II}.
Fig. 12.—*V. cunninghamii* (n = 24), first anaphase of meiosis.

Fig. 13.—*Melicytus ramiflorus* (n = 16), 16^{II}.
Fig. 14.—*M. lanceolatus* (n = 16), 16^{II}.
Fig. 15.— *M. macrophyllus* (n = 16), 16^{II}.
Fig. 16.—*M. micranthus* (n = 48), 48^{II}.
Fig. 17.—*Hymenanthera chathamica* (n = 16), 16^{II}.
Fig. 18.—*H. novae-zelandiae* (n = 16), 16^{II}.
Fig. 19.—*H. obovata* (n = 16), 16^{II}.
Fig. 20.—*H. angustifolia* (n = 16), 16^{II}. See also Fig. 26.
Fig. 21.—*H. alpina* (n = 32), 32^{II}. Note secondary association.
Fig. 22.—*H. crassifolia* (n = 32), first anaphase of meiosis.



Figs 23–27.—All × 1500.

Fig. 23.—*Fuchsia excorticata* (n = 11), 11^{II}, first metaphase of meiosis.

Fig. 24.—*F. perscandens* (n = 11), first anaphase of meiosis.

Fig. 25.—*F. procumbens* (2n = 22), mitotic metaphase.

Fig. 26.—*Hymenanthera angustifolia* (n = 32), 32^{II}, first metaphase of meiosis. Note secondary association.

Fig. 27.—*Viola filicaulis* (n = 36), 36^{II}, first metaphase of meiosis.

CORRIGENDA

N.Z. J. Sci. 1 : 413

in line 7 under PROCEDURE 100 ml should read 100 μl.

Ibid. 2 : 33

The last two lines in the key to species of *Eriococcus* should read—

6(1) Anal lobes with 4 dorsal setae *gibbus*
Anal lobes with 3 dorsal setae *milleri*

Ibid. 2 : 156

Caption to Fig. 30 should read—

Myoporum laetum (n = 54), first metaphase of meiosis, 2^{VI} 4^{IV} 1^{III} 38^{II} 1^{I}, × 1500.

Caption to Fig. 31 should read—

Brachyglottis repanda (n = 30), diakinesis, 30^{II}, × 1500.

Ibid. 2 : 262

Table 1

C.I. No. 640, under Fluorescence, yellow should be inserted.
C.I. No. 13011, under Fluorescence, yellow should be deleted.
C.I. No. 79, under Fluorescence, dull orange-red should be inserted.

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